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CONTRACTOR REPORT

TRANSIENT REACTIVE EXHAUST FLOW FROM
A RING-SYMMETRIC HF/DF SPACE LASER

by

Joseph Falcovitz

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ABSTRACT

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NOMENCLATURE followed by units (if any)

A	cross-section area (of diffuser or nozzle)
A_v	Avogadro's number 6.022×10^{26} (molecules/kmole)
C	sound speed (m sec ⁻¹)
E	total energy per unit volume (MJ m ⁻³)
f_X	mole fraction of species X at diffuser entrance
g_c	rate of hydrogen recombination collisions (with HF or DF) per unit volume (m ⁻³ sec ⁻¹)
k_0	hydrogen recombination rate constant [(mole/cm ³) ⁻² sec ⁻¹]
k_1	modified hydrogen recombination rate constant [(kg/m ³) ⁻² sec ⁻¹]
M	Mach number
n	number density (molecules/m ³)
P	pressure (Pa)
Q_H	formation energy of H ₂ (KJ/mole)
Q_{DET}	hydrogen recombination energy release parameter (MJ/kg)
t	time (ms)
T	temperature (K)
U	flow velocity (m/sec)
W	average molecular weight (kg/kmole)
x	radial coordinate (in diffuser)
Z	normalized mole fraction of H (Z = 1 at diffuser entrance)
α	turning angle of flow velocity in a corner expansion to vacuum
$\Delta\alpha$	turning angle increment for transient corner expansion
γ	specific-heat ratio
ρ	density (kg m ⁻³)
θ	inclination of flow velocity vector (to x-axis)
Γ	the fraction $(\gamma + 1)/(\gamma - 1)$
[X]	molar density of species X (kmole m ⁻³)

INDICES

- ()₀ stagnation conditions
- ()₁ nozzle (diffuser) exit conditions
- ()₂ diffuser entry conditions
- ()_t Eulerian time derivative
- ()_x Eulerian space derivative
- ()[•] Lagrangian time derivative

1. INTRODUCTION

In recent years a study of the gasdynamics of space-based HF/DF laser exhaust plume was conducted at the NPS. The aim of this program was to identify phenomena that give rise to a potentially contaminating backflow of corrosive species (HF, DF, F), and to estimate the magnitude of the flux arriving at the spacecraft [1, 2, 3, 4]. The laser was envisioned as a cylindrical spacecraft having a centrally located nozzle of ring-symmetry. This is an idealization of a more general zero-thrust exhaust configuration for an open loop HF/DF laser (Fig. 1-1).

In former studies [2, 3] we focused on the contribution of thermal self-scattering to a contaminating backscattered flux of corrosive molecules (HF, DF) from the exhaust plume. It was shown that this flux emanates primarily from the lip-centered rarefaction fans that flank the exhaust plume, and it was estimated that at a sufficiently high exit Mach number (e.g. $M_1 = 4$), the thermally backscattered flux of HF + DF is utterly negligible.

The purpose of this report is to present a study of the effect of diffuser start-up flow, including the ongoing recombination of atomic hydrogen, on the thermally backscattered flux. Our main conclusion is that by designing for a sufficiently high steady exit Mach number (e.g. $M_1 = 4$), the level of thermally backscattered flux of corrosive molecules (HF + DF) would be negligible even when the combined effects of hydrogen recombination and transient flow are considered.

The diffuser is simplified as a cylindrically expanding channel of uniform width, and the flow is idealized as inviscid expansion of a perfect gas with an ongoing reaction of hydrogen recombination. The flow is computed as one-dimensional time-dependent.

A fully 2-D time-dependent computation of an emerging exhaust plume is outside the scope of the present laser exhaust study. Rather, we resort to semi-quantitative arguments that lead to an upper-bound estimate of the effect of transient flow on thermal backscattering, by showing that the transient turning angle in an expansive corner flow can be estimated as higher than the corresponding steady flow turning angle. It is subsequently suggested that an overestimate to the the backscattered flux from a transient plume is obtained by considering it as a steady plume whose exit velocity vector is pre-rotated so that its limiting (vacuum) streamline coincides with that defined by the transient turning angle.

The plan of this report is the following. In Ch. 2 we present our radial (1-D) diffuser model based on the linear configuration of the TRW test laser [5] , and we propose a "typical case" of HF/DF laser flow based on one of those tests. Ch. 3 is devoted to the gasdynamic governing equations, including the hydrogen recombination rate. The resulting diffuser model was implemented in a 1-D Euler code (named HFL) which utilizes the GRP scheme for integrating the conservation laws of compressible flow [6] . The HFL code is given in Appendix A. The results of a typical diffuser start-up flow are presented in Ch. 4, along with a discussion and analysis of the effects of transient flow and uncertainty in the hydrogen recombination rate on thermally backscattered flux of HF + DF. We also consider kinetic backscattering of HF or DF molecules caused by third-body recoil in the hydrogen recombination reaction. It is shown that the combined contribution of these effects to backscattered flux remains negligible in the typical case. Chapter 4 ends with some concluding remarks, and references are brought in Ch. 5.

SPACE - BASED HF LASER

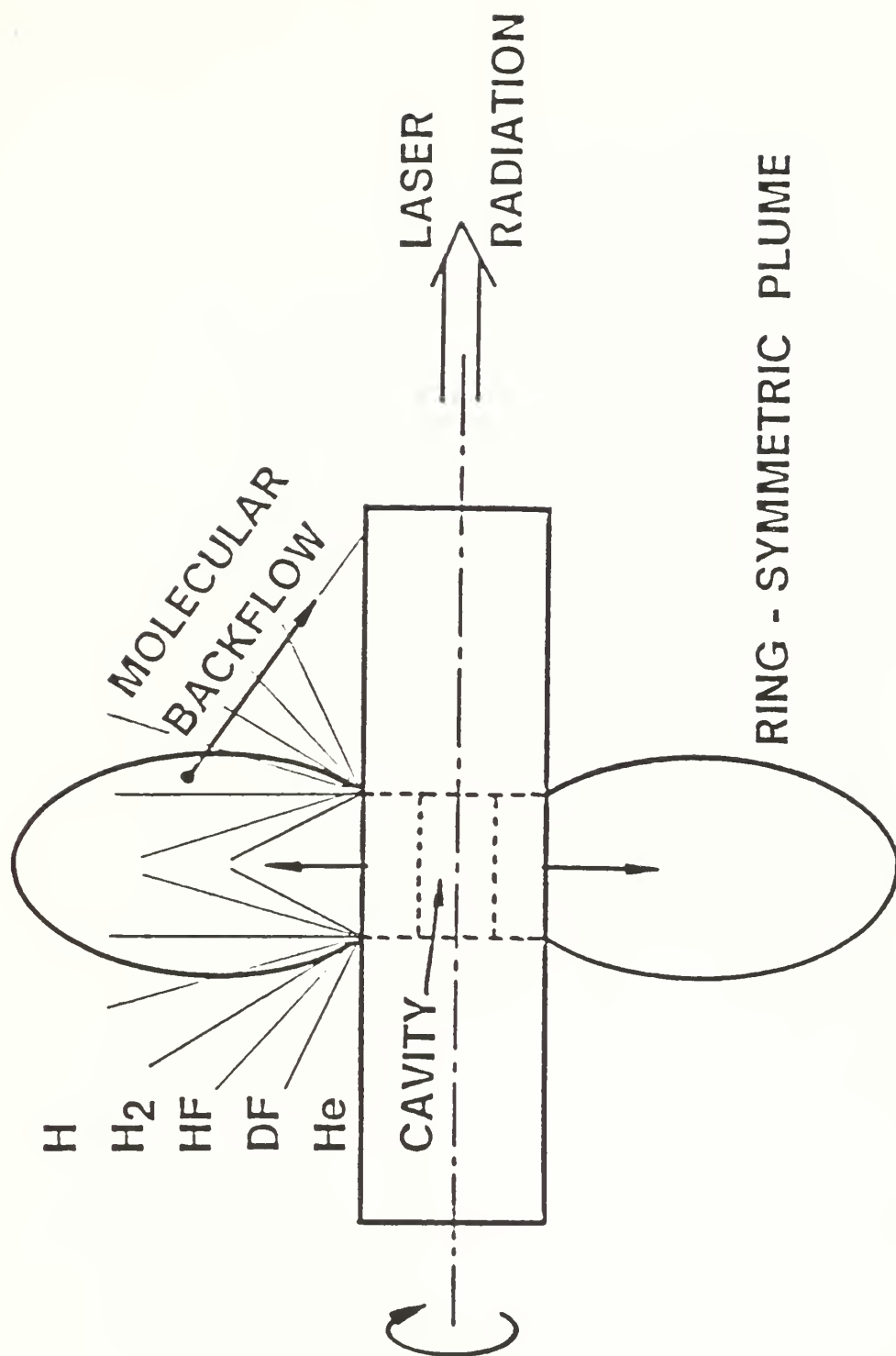


Figure 1-1. Ring-Symmetric HF DF Laser Exhaust Plume

2. THE DIFFUSER FLOW MODEL

Our diffuser model is based on a schematic radial laser configuration as shown in Fig. 2-1. The major components in this design concept are those present in an experimental HF/DF open loop laser tested at TRW [5]. In this chapter we describe the radial configuration including the diffuser (Section 2.1), then we present a typical HF/DF laser flow based on one of those TRW tests (Section 2.2).

2.1 Radial Laser Configuration

We assume that an open loop HF/DF laser of the type tested at TRW [5], can be rearranged in a radial (rather than linear) sequence, where the flow begins at the hub and proceeds in an outward radial direction. Referring to Fig. 2-1, the major components of this configuration are :

- (a) Combustion Chamber : Deuterium and fluorine burn with excess fluorine, resulting in hot gaseous mixture where fluorine is virtually completely dissociated.
- (b) Nozzle Cascade : Rapid expansion to supersonic flow leaves atomic fluorine concentration effectively frozen.
- (c) $\text{H}_2 + \text{He}$ Injection : Mixture is injected between the supersonic streams of $\text{DF} + \text{F}$ emerging from the cascade.
- (d) Mixing and Lasing : The lasing is from vibrationally excited HF molecules produced by direct reaction between H_2 and F . As a by-product, one H atom is produced for every HF molecule.
- (e) Diffuser Entrance : This point marks the end of the lasing process. From this point on the flow is just an exhaust to be discarded safely.
- (f) Radial Diffuser : The purpose of the diffuser is to raise the flow Mach number at the exit so that no appreciable backflow from the exhaust plume will take place [2, 3, 4]. It should be noted that a desirable diffuser area ratio can be achieved at lower radius ratios by letting the diffuser expand in the axial direction.

2.2 Typical Laser Flow

We chose as a typical laser flow one of the tests conducted in the TRW experiments [5] it is test III in Table 5 (p. 91) of that reference. The mole fraction and corresponding average molecular weight and specific-heat ratio (W and γ) at the diffuser entrance for this test were :

Mole fractions	$f_H = .091$ $f_{HF} = .091$ $f_{H_2} = .104$ $f_{DF} = .135$ $f_{He} = .579$	(2.2-1)
Average molecular weight	$W = 7.27$	
Specific-heat ratio	$\gamma = 1.54$	

The additional data required for the computational model is the flow variables at the diffuser entrance. Some of these variables have been measured directly or indirectly and the remaining variables can be evaluated from standard isentropic flow relations for compressible flow of an ideal gas. The data given in the TRW tests report [5] are :

Diffuser entrance cross-section is : $1'' \times 7''$

Mass flow rate is : $14.99 \text{ (gr sec}^{-1}\text{)}$ (2.2-2)

Stagnation temperature is : 1400 (K)

Flow velocity is : $2300 \text{ (m sec}^{-1}\text{)}$

Flow density is now obtained as the ratio of the specific mass flow rate and the velocity. Then Mach number is extracted from the standard relations between Mach number, velocity and stagnation temperature. The values of these variables are :

$$M_2 = 2.26$$

$$\rho_2 = 1.44 \times 10^{-3} \text{ (kg m}^{-3}\text{)} \quad (2.2-3)$$

$$P_2 = 9.72 \times 10^{-4} \text{ (MPa)}$$

The flow at the diffuser entrance is thus fully specified for the selected typical case. In the next chapter we take up the matter of computing the transient expansion following an abrupt start-up of the diffuser inflow.

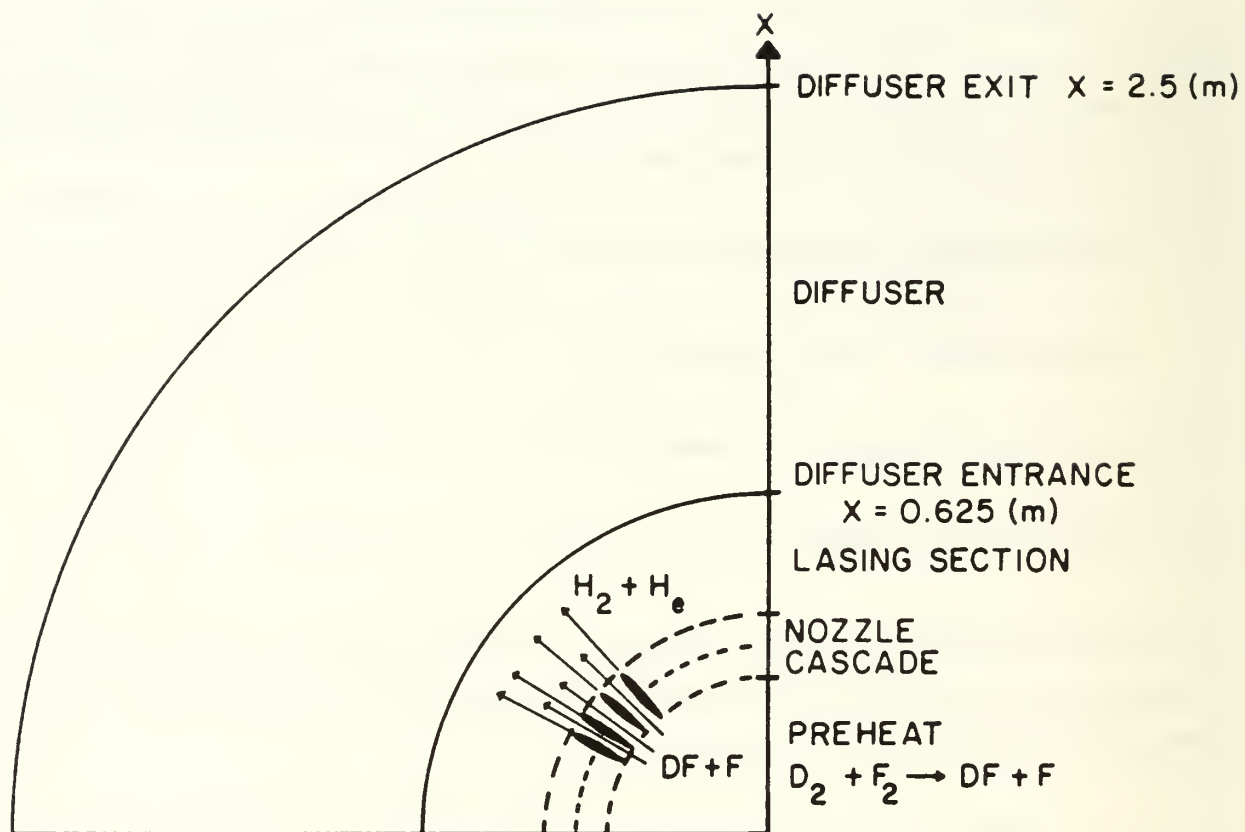


Figure 2-1. Radial Configuration of HF/DF Open-Loop Laser

3. THE GASDYNAMIC FLOW MODEL

The transient expansion of the lasing products following an abrupt start-up of inflow at the diffuser entrance, is idealized as an inviscid compressible flow of a mixture of perfect gases with one ongoing chemical reaction — that of hydrogen recombination. The computational model thus calls for a formulation of the governing equations and for a numerical scheme capable of integrating them in time and space.

In this chapter we describe the governing equations for the diffuser flow (Section 3.1), following by a simple approximation chosen for the hydrogen recombination rate as a three body reaction (Section 3.2). The numerical scheme employed for the solution is of the Generalized Riemann Problem (GRP) type [6] . This scheme has been implemented in a code which was adapted to the diffuser flow case. The code (named HFL) and some brief description of features introduced to treat hydrogen recombination are given in Appendix A. In a recent report [7] a very similar version of this code (without chemical reaction) was described in considerable detail.

3.1 The Governing Equations

The expansion of lasing products through the diffuser is governed by the Euler equations for a gaseous mixture of ideal gases with ongoing hydrogen recombination reaction. We write these equations in the quasi-one-dimensional format of flow in a stream tube of varying cross-section area $A(x)$, but in actual computations we set $A(x)=x$, thereby reducing the equations to the cylindrical case. (The code HFL, however, can accept any smooth $A(x)$).

We chose to simplify the designation of atomic hydrogen mole fraction by normalizing it as $f_H Z(x,t)$, where f_H is the mole fraction at the diffuser entrance (it is constant) and $Z(x,t)$ denotes the degree of dissociation ($Z=1$ is maximum concentration of H at the diffuser entrance, $Z=0$ is complete recombination). As an approximation, we assume that W and γ are constant throughout. In the typical case (2.2-1), γ and W can vary by as much as 1% and 4% respectively at full recombination. Neglecting that variation is consistent with the preliminary nature of the present diffuser flow analysis.

The governing equations are the three standard conservation laws (mass, momentum and energy), and an additional species conservation law for atomic hydrogen. The conservation laws are

augmented by an equation of state (ideal gas) and by a rate law for hydrogen recombination. The full system of equations is :

$$\begin{array}{ll}
 \text{Mass} & [\rho]_t + [\rho U]_x = 0 \\
 \text{Species H} & [\rho Z]_t + [\rho U Z]_x = \rho \dot{Z} \\
 \text{Momentum} & [\rho U]_t + [\rho U^2]_x + \rho P_x = 0 \\
 \text{Energy} & [E]_t + [E + P]U_x = 0 \\
 \text{Equation of State} & P(\rho, E, Z) = (\gamma - 1) [E - \rho U^2/2 - (\rho f_H Z/W) Q_H] \\
 \text{Recombination Rate} & \dot{Z} = \dot{Z}(\rho, P, Z)
 \end{array} \tag{3.1-1}$$

where A is a function solely of x , and ρ , U , P , E , Z are all functions of (x, t) . The normalized rate function is \dot{Z} . Its derivation and explicit expression are given in Section 3.2.

We note that the energy equation contains the heat released by hydrogen recombination (Q_H per mole of H) in an implicit way, by defining the total energy as including the latent heat due to recombination, in addition to internal and kinetic energy terms.

3.2 Hydrogen Recombination

The hydrogen recombination is commonly assumed to be a three-body reaction [8] , with the following rate law :



$$[\dot{H}_2] = -k_0 [H]^2 [M] \tag{3.2-1}$$

$$k_0 = 7 \times 10^{15} \text{ [(mole/cm}^3\text{)}^{-2} \text{ sec}^{-1}]$$

where by **M** we denote a third molecule, which in our case may be any molecule in the gaseous mixture (including **H**).

The value we chose for k_0 is an upper limit of a range of values recommended by Kondratiev [9] for the reaction $\text{H} + \text{H} + \text{He}$ (from 2×10^{15} to 7×10^{15}), since in the typical case helium constitutes about 58% of the molecules in the lasing products.

The data compiled by Kondratiev [9] indicates a comparable range of variation with temperature as with the third species **M**. We later introduce uncertainty factors of 10 and 100, which in all likelihood more than reflect the uncertainty in the reaction rate for hydrogen recombination.

It is convenient to redefine the reaction rate in terms of flow density ρ and normalized **H** concentration Z . The modified rate constant k_1 is given by :

$$\begin{aligned} \dot{Z} &= - k_1 \rho^2 Z^2 \\ k_1 &= 2 k_0 f_H / W^2 \end{aligned} \tag{3.2-2}$$

where the factor 2 is due to the fact that the rate of depletion of **H** is twice the rate of production of H_2 . In deriving (3.2-2) we made use of the relations $f_H = [\text{H}]_2 / [\text{M}]_2$ and $[\text{M}] = \rho / W$, where index 2 denotes the diffuser entrance.

The heat of formation released per mole of recombined H_2 is 435.783 (kJ/mole) according to [10] (page F-179 in that reference). In the code we use the energy parameter per unit mass of the gaseous mixture Q_{DET} , defined as :

$$\begin{aligned} Q_{\text{DET}} &= Q_H f_H / W \\ Q_H &= 435.783 / 2 \quad (\text{KJ/mole}) \end{aligned} \tag{3.2-3}$$

4. RESULTS AND DISCUSSION

Several numerical computations of the transient diffuser flow were performed using the code HFL (Appendix A). The flow was started by an abrupt inflow at the diffuser inlet; the radial diffuser model and the typical HF/DF laser case (Sections 2.1 and 2.2) were assumed. Due to uncertainty in hydrogen recombination rate, three rate levels were assumed: the nominal level (3.2-1), a tenfold increased rate and a hundredfold increased rate.

We are primarily concerned with the thermally backscattered flux arriving at the surface from the exhaust plume. Our goal is to show that by choosing a diffuser with a sufficiently high steady exit Mach number, the backscattered flux can be negligibly low even when the combined effects of hydrogen recombination and transient exit flow are taken into account. Put in other words, we present a simplified analysis of the transient exhaust flow, which enables the establishment of a reasonable margin on a frozen/steady design for low backscattered flux. This analysis is presented in Section 4.1 below.

The continuation of the hydrogen recombination reaction into the plume may give rise to a contaminating backflow of a different kind. The velocity imparted to the "third body" molecule in the hydrogen recombination process (Eq. 3.2-1) may be large enough to overcome the radial flow velocity component, resulting in molecular backflow. This effect is discussed in Section 4.2, and it is shown to be potentially capable to give rise to an HF/DF deposition rate of the order of 1 molecular monolayer per hour.

4.1 Thermal Backscattering

Since in steady flow thermally backscattered flux is linked primarily to exit Mach number, we focus our attention on the time-history of the exit Mach number obtained from the diffuser start-up computations mentioned above. Two major features are noted in these results (Fig. 4-1).

The first feature is the monotonic decrease in exit Mach number with time, as the flow within the diffuser undergoes transition from an initial "cloud expansion" mode to a steady expansion flow in a channel of increasing cross-section area. A steady exit flow seems to be established after about 2 (ms) from the start-up instant. The second feature is related to the heat released in the flow by hydrogen recombination. As the recombination rate is increased, so does the time-asymptotic value

of the exit recombination fraction. The recombination fractions in the three cases (Fig. 4-1) are 1%, 7% and 46%; the corresponding exit Mach numbers are 4.0, 3.69 and 2.81. This trend is in qualitative agreement with the well known phenomenon of decrease in Mach number as a result of heat addition to a steady supersonic flow in a channel of uniform cross-section [11] .

Estimates of recombination rates are notoriously uncertain. How can a reasonable uncertainty factor be established? We do not know of an estimate of this factor for the flow of HF/DF laser products. However, in another case of flow involving hydrogen recombination - that of hydrazine rocket motors - a recent study [12] recommends a hydrogen recombination rate of $2.8 \times 10^{17}/T$ (in c.g.s. K units) and an uncertainty factor of 30. Assuming the relatively low temperature of $T = 300$ (K) and multiplying by 30, we get a recombination rate of 3×10^{16} , versus 7×10^{16} in our tenfold case. This demonstrates that the tenfold case is already reasonably high; just the same, we also retain the hundredfold case in the upcoming discussion.

The exit Mach number time-histories (Fig. 4-1) demonstrate that the nominal diffuser flow is nearly frozen (exit recombination fraction 1% and Mach number 4); even in the tenfold case the flow is not dominated by hydrogen recombination (exit recombination fraction 7% and Mach number 3.69). This conclusion is in agreement with findings of the TRW HF/DF laser study [5] . It takes the unrealistically high hundredfold increase in hydrogen recombination rate to produce a decisive change in the steady diffuser flow (exit recombination fraction 46% and Mach number 2.81).

One role of the diffuser is to expand the laser exhaust to a sufficiently high exit Mach number, so that the thermally backscattered flux of corrosive molecules (HF, DF) is negligibly small. Let us consider the nominal case ($M_1 = 4$) and denote by "reference flux" the combined HF+DF backscattered flux arriving at a point located at 0.1 (m) from the nozzle lip (Fig. 1-1). Using the code RINGBD based on the breakdown surface model [2] , the nominal reference flux was evaluated as 3.1×10^5 (molecules $m^{-2} sec^{-1}$). This flux level corresponds to a surface deposition rate (assuming the sticking coefficient equals 1) of about 10^{-10} molecular monolayers per hour, which is utterly negligible (a reasonable estimate of total operating time would not exceed several hours).

Observing that a steady exit flow has been established in all three cases by about $t = 2$ (ms) (see Fig. 4-1), we suggest that an approximate estimate of the backscattered flux would be obtained by assuming a steady flow at the diffuser exit and the exhaust plume. The RINGBD computations of the increase hydrogen recombination rate cases yielded the following results. In the tenfold case ($M_1 = 3.69$) the flux was 10^2 times larger than the nominal reference flux. In the hundredfold case

($M_1 = 2.81$) the flux increase was by a factor of 10^7 . Even in the unrealistically high hundredfold case, that flux level corresponds to about 10^{-3} monolayers per hour, which is still negligible.

What other uncertainties could affect the foregoing conclusion? First we consider the effect of variations in stagnation temperature and density relative to the nominal case, then we take up the matter of transient plume flow.

Exit stagnation temperature was observed to vary in the HFL diffuser start-up computations by a factor of no more than about 1.3. Since all velocities in the breakdown surface model are normalized by speed of sound [2], the flux is proportional to the square root of the stagnation temperature. Also, it has been shown [2] that a change in stagnation density can produce an inversely proportional change in flux. Stagnation density was reduced by a factor of about 1.3 in the tenfold case and about 2.8 in the hundredfold case. In either case the potential effect on flux is small relative to changes brought upon by reduced exit Mach number, so we attribute the drastic change in flux following an increased hydrogen recombination rate primarily to the reduced exit Mach number.

We now address the effect of transient plume flow. Since the exit Mach number is monotonically decreasing with time (Fig. 4-1), and since other flow variables do not appreciably affect the flux from a steady plume, we suggest that an upper bound on the effect of transient plume flow can be established by linking it to a "transient turning angle", larger than that corresponding to a steady flow with the same exit Mach number. Obviously, if a Prandtl-Meyer flow pattern is derived from a flow which exits the nozzle at an angle lower than 90° , its limiting turning angle would bring it closer to the spacecraft surface, and with a lower outward radial velocity to overcome, more molecules would be thermally backscattered. Thus, we regard the transient flow around the nozzle lip as represented by an equal exit Mach number steady flow, with some initial exit turning angle.

The justification for this model is the following "upper bound" estimate for the transient turning angle of an emerging exhaust plume. The exit velocity vector U_1 is visualized as rotating by a gradual turning of the plume/vacuum interface until it reaches the normal velocity $(2/(\gamma-1))C_1$ (Fig. 4-2), which corresponds to a plane-wave expansion into vacuum. The corresponding turning angle is $\alpha = (2/(\gamma-1))C_1/U_1 = (2/(\gamma-1))/M_1$. It is an overestimate of the turning angle since in a steady corner expansion (and also in a nonsteady one) the magnitude of the velocity vector increases as it rotates, in order to conserve stagnation enthalpy (or even increase it in nonsteady flow about an expansive corner).

It is of interest to note that α as given above is identical with the first term of a power series expansion in $1/M_1$ of the standard Prandtl-Meyer expression for the limiting turning angle [13] . Let us denote by $\Delta\alpha$ the increment of the unsteady turning angle relative to the corresponding steady one (Prandtl-Meyer). This (positive) increment is given by :

$$\Delta\alpha = (2/(\gamma-1))/M_1 - \left\{ \Gamma^{1/2} \arctan\left[\Gamma^{1/2}(M_1^2-1)^{-1/2}\right] - \arctan\left[(M_1^2-1)^{-1/2}\right] \right\} \quad (4.1-1)$$

$$\Gamma = (\gamma+1)/(\gamma-1)$$

We now argue that the flux ratio between a steady flow and the same flow with exit velocity rotated by $\Delta\alpha$ is an upper-bound estimate to the effect of transient plume flow with the same exit variables. We note that by pre-rotating the steady corner flow, we make the limiting streamline in the steady case, coincide with the nonsteady plume/vacuum interface deemed to have rotated through the angle α .

The stage is now set to estimate the transient flux increase factors in the three hydrogen recombination rate cases (exit Mach numbers **4**, **3.69** and **2.81**). Using Eq.(4-1) we get the turning angle increments of $\Delta\alpha = 4.1^\circ$, 5.1° and 10.6° respectively. Re-computing the reference flux (code RINGBD) in these cases with initial exit angle of $90^\circ - \Delta\alpha$, we get the flux increase factors of **2.7**, **3.5** and **10** respectively. Even in the worst case (hundredfold), the flux would increase from 10^{-3} to 10^{-2} monolayers per hour, which is still negligibly small.

We also notice that the flux increase factor resulting from the decrease in exit Mach number due to higher hydrogen recombination rate, is much larger than the factor representing the effect of transient plume flow in the same case. Thus, in the tenfold case these factors are 10^2 versus **3.5**, and in the hundredfold case the ratio is even higher : 10^7 versus **10**. We conclude that the transient effect is quantitatively secondary to the effect of exit Mach number, which is thus established as the major parameter for designing an exhaust with a negligible level of thermally backscattered HF + DF flux.

4.2 Kinetic Backscattering

The role of the third body in the hydrogen recombination reaction (3.2-1) is to absorb the energy released by the recombination process while maintaining the combined pre-collision momentum of the participating molecules. Assume the momentum added to $[M]$ is q , then the momentum added to H_2 is $-q$. Denote by m_1 the mass of H_2 , by m_2 the mass of HF and by e the energy released due to the recombination. Then q is determined from the following energy conservation relation :

$$q^2/2m_1 + q^2/2m_2 = e \quad (4.2-1)$$

$$m_1 = 2 \quad m_2 = 20 \quad e = 4.36 \times 10^8 \text{ (Joules, kmole)}$$

$$U = q/m_2 = 2000 \text{ (m/sec)}$$

The values used in the computation above are per kmole, but the result is the same as using values pertaining to single molecules. Since the velocity obtained upon expansion to zero-pressure in the typical case is about 3000 (m/sec), our results imply that a turning angle in excess of $\arccos(2/3) = 48^\circ$ is needed in order to enable some kinetically backscattered molecules to reach the spacecraft.

In the nominal case the turning angle is 49° and in the tenfold case it is 52° . Also, some kinetically backscattered molecules can originate from within the rarefaction fan, since the exit velocity in the typical case is only about 1500 (m sec⁻¹) (versus 2000 (m sec⁻¹) velocity increment to kinetically scattered HF molecules). Consequently, this effect may contribute to spacecraft contamination, and its magnitude should be estimated. It will become progressively more significant at lower exit Mach number, and thus may be an additional factor in determining a minimal value of this flow variable.

While we do not presently attempt at an exact integration of the flux of kinetically backscattered molecules arriving at each surface point, we propose the following overestimate of its magnitude. Consider the outgoing flux of kinetically scattered HF molecules from a half-space of quiescent uniform gas having the thermodynamic properties of the nozzle exit in the typical case. Consider the hydrogen recombination rate equation (3.2-1), and substitute $[X] = f_X n / A_v$. This equation then reads as the volume rate of hydrogen recombinations (denoted as g_c below). In a slab of quiescent gas, half the kinetically scattered molecules have an outward pointing velocity vector in one direction. The probability of collisionless passage out of the slab is $\exp(-x/\lambda)$, so that the outgoing flux F is given by :

$$F = g_c \lambda / 2$$

(4.2-2)

$$g_c = k_0 n^3 A_v^{-2} f_H^2 (f_{HF} + f_{DF})$$

Using typical case exit conditions $n_1 = 2.81 \times 10^{22} \text{ (m}^{-3}\text{)}$ and mean free path $\lambda_1 = 1.28 \times 10^{-4} \text{ (m)}$, we get $F = 5.14 \times 10^{16} \text{ (m}^{-2} \text{ sec}^{-1}\text{)}$, or about 12 monolayers per hour. Since only a small fraction of this flux actually arrives at spacecraft surface points, the arriving flux is in all likelihood well below 1 monolayer per hour. If this flux level is deemed significant, an accurate integration of kinetically scattered flux emanating from the exhaust plume should be performed. The details of such scheme are analogous to the first-collision ambient scattering model [4], since both effects result in a source-like distribution throughout the plume, and both involve a steric factor (one half in the quiescent gas above) related to the vector addition of flow velocity and velocity imparted through ambient collision or assistance in hydrogen recombination. Therefore, the two effects can conveniently be unified under a common framework.

4.3 Concluding Remarks

From the foregoing analysis and discussion we conclude that a design for low (negligible) level of thermally backscattered flux of HF+DF can be accomplished by assuming steady frozen exhaust flow. The effects of transient diffuser/plume flow and hydrogen recombination may typically increase that flux by a factor of 10^2 . Given the sensitivity of flux to exit Mach number, an adequate margin can readily be achieved by raising the exit Mach number. In the typical case presented here, an exit Mach number of 4 has been shown to be adequate.

It should be noted that transient effects originating from points upstream of the diffuser entrance were not considered here, as they depend on details of the system construction and operating sequence.

The kinetic scattering effect has been pointed out as an additional potential source of contaminating backflow. It is the result of hydrogen recombination collisions assisted by an HF or DF molecule as third body. The HF/DF molecule receives part of the kinetic energy release by the hydrogen recombination.

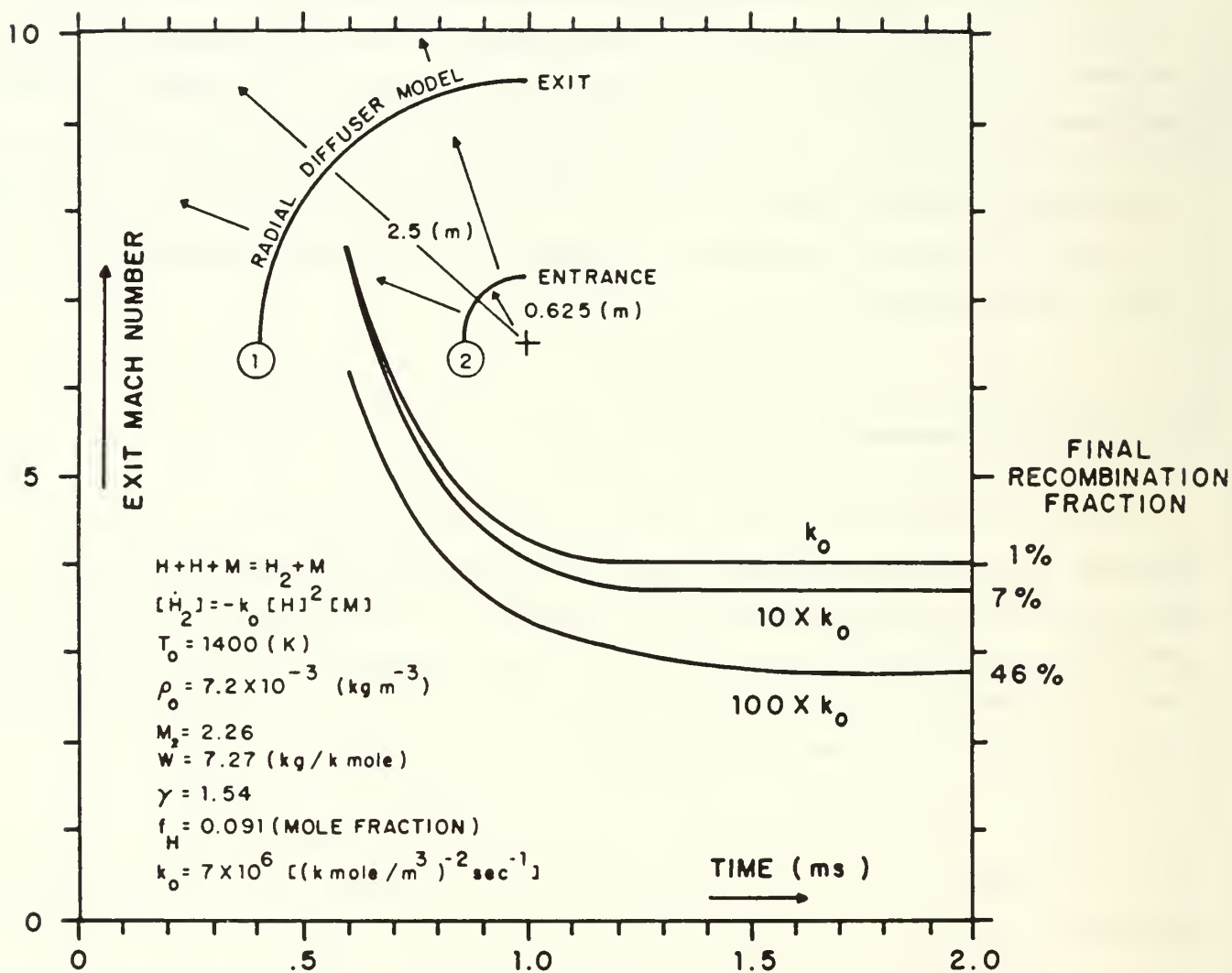


Figure 4-1. Mach Number at Diffuser Exit for Reactive Transient Flow

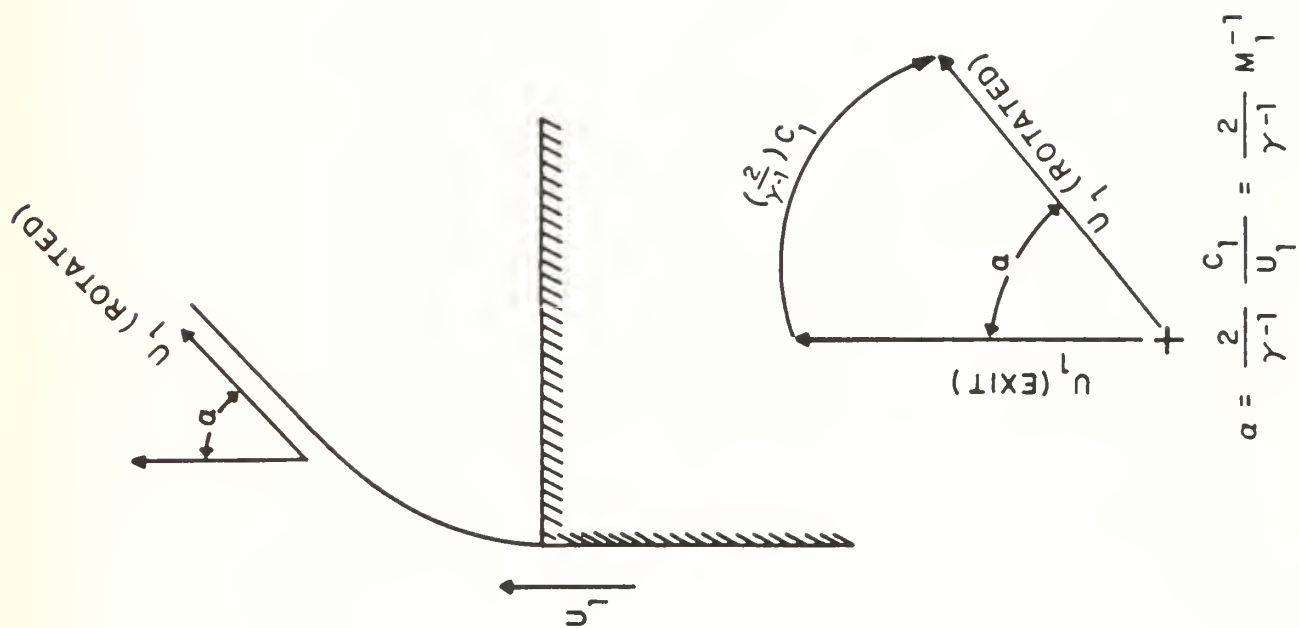


Figure 4-2. Rotation Angle for Non-Steady Plume (Overestimate)

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APPENDIX A. The HFL Code

A.1 Features Specific to Diffuser Flow Model

The purpose of this appendix is to provide the listing of the HFL code used in the diffuser flow computations. An almost identical code was recently described in some detail [7], the major modification for HFL being the addition of hydrogen recombination.

The highlights of the HFL version to the GRP code [7] are as follows (numbers in parenthesis refer to statement numbers which are prefixed by HFL in the listing).

(a) Data (NETUNM) :

The data which relates specifically to the diffuser flow with hydrogen recombination is given in statements (194 - 239). Some parameters are stored in /DIFFUS/ (129) for use in BEGIN and SAFAE.

(b) Initial Conditions (BEGIN) :

The initial conditions are ideally an empty diffuser. As an approximation we set small pressure and density (270 - 271) and a positive velocity (277) as initial values. The velocity reduces the intensity of the shock driven into the dilute initial gas by the abrupt start-up of inflow at the diffuser entrance ($I = 2$). Note that the initial value of the total energy $E(I)$ is augmented by the heat of formation of hydrogen (306). The heat term is subsequently subtracted from the total energy in order to compute the pressure (see (d) below).

The grid is defined as follows. The number of cells ($L-2$) is $L-2 = 50$ (24). The diffuser extends from $X_0 = 0.625$ to $X_1 = 3.125$ (283 - 284), so that $DX = 0.05$. Since the external radius of the spacecraft is just 2.5, this grid consists of 40 cells within the diffuser and 10 cells in an extended segment. The purpose of this extended segment is to minimize any propagation of error due to imperfection of the outflow boundary condition (see (c) below). Since the ambient pressure is zero, this additional segment does not affect the flow at $X \leq 2.5$. Consequently, the results for the diffuser exit flow were read from cell $I = 39$ whose midpoint is $X = 2.5$.

(c) Boundary Conditions (SAFAE) :

The inflow is set by assigning the diffuser entrance conditions to cell $I = 1$. The outflow is set by extrapolating (with zero gradient) the flow from the inner boundary cell ($I = L-1$) to the boundary cell $I = L$.

(d) Conservation Laws (CYCEUL) :

Here all four conservation laws are integrated in time. There is an added equation of a "time-split" scheme for solving the conservation of **H** species equation. It is first solved without the recombination rate term (459), then the change in $Z(I)$ due to recombination during that time step is added as DZZ (501 - 502).

The energy equation includes the contribution of the formation energy indirectly. This equation has the same format as the adiabatic one (491), but when QDET.GT.0, the internal energy (505) is affected by changes in $Z(I)$ and as a result the pressure $P(I)$ (516) is also affected by progress in the recombination reaction.

A.2 Code Listing

```

C$OPTIONS LIST
IMPLICIT REAL*8(A-H,O-Z,$)
C PROGRAM DETO
C HFL -- HF/DF LASER DIFUSER TRANSIENT FLOW.
COMMON B(52,26)
1 ENDB
COMMON /AB/A(50)
EQUIVALENCE (L,A(1)),(LL,A(2)),(T,A(3)),(DT,A(4)),(TMAX,A(5)),
1 (TMUD,A(6)),(DTMUD,A(7)),(JOB,A(8)),(NERI,A(9)),
2 (JJJ,A(10)),(KEYMON,A(11)),(NCYC,A(12))
EQUIVALENCE (COLELA,A(13))
EQUIVALENCE (LAGEUL,A(14))
EQUIVALENCE (UGAL,A(15))
EQUIVALENCE (KEYEK,A(16))
EQUIVALENCE (NCYCPR,A(17))
EQUIVALENCE (STAB,A(18)),(DTBA,A(19)),(DTKOD,A(20)),(KDT,A(21))
COMMON /MONIT/NC14(4),CASEAV(4),NF16(6),
1 NMONU(4),NMONP(4),NMONG(4),NMONRO(4),NMONZ(4)
C*****
C DO 20 N=1,30
C20 NC14(N)=0
NMAT=26
C L=(LOC(ENDB)-LOC(B(1,1)))/NMAT
L=52
LL=L-1
NN=NMAT*L
DO 1 I=1,L
DO 1 II=1,NMAT
1 B(I,II)=0.
CALL MAINO(L,B(1,1),B(1,2),B(1,3),B(1,4),B(1,5),
1 B(1,6),B(1,7),B(1,8),B(1,9),B(1,10),
2 B(1,11),B(1,12),B(1,13),B(1,14),B(1,15),
3 B(1,16),B(1,17),B(1,18),B(1,19),B(1,20),
4 B(1,21),B(1,22),B(1,23),B(1,24),B(1,25),
5 B(1,26))
STOP
END
SUBROUTINE MAINO
1 (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,
2 US,PS,UIDOT,PIDOT,
* FIMZ,ZMDOT,
3 TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ)
IMPLICIT REAL*8(A-H,O-Z,$)
DIMENSION X(L),U(L),P(L),RO(L),G(L),E(L),DU(L),DP(L),DRO(L),
1 DG(L),DXSI(L),MIN(L),
2 US(L),PS(L),UIDOT(L),PIDOT(L)
3 ,TENA(L),FIRO(L),FIM(L),FIE(L)
4 ,GIP(L),VOL(L),Z(L),DZ(L)
5 ,FIMZ(L),ZMDOT(L)
COMMON /AB/A(50)
EQUIVALENCE (LL,A(2)),(T,A(3)),(DT,A(4)),(TMAX,A(5)),
1 (TMUD,A(6)),(DTMUD,A(7)),(JOB,A(8)),(NERI,A(9)),
2 (JJJ,A(10)),(KEYMON,A(11)),(NCYC,A(12))
EQUIVALENCE (LAGEUL,A(14))
EQUIVALENCE (NCYCPR,A(17))
EQUIVALENCE (STAB,A(18)),(DTBA,A(19)),(DTKOD,A(20)),(KDT,A(21))
COMMON /TOT/AMTOT,ETOT,EKTOT,EPTOT,TENTOT
C*****
T=0.
NCYC=0
JJJ=0
CALL NETUNM
DELT=DT
CALL BEGIN
1 (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,
2 US,PS,UIDOT,PIDOT,
* FIMZ,ZMDOT,
3 TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ)
CALL SAFAE
1 (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,
2 US,PS,UIDOT,PIDOT,
* FIMZ,ZMDOT,

```



```

3          TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ)
1  NCYC=NCYC+1
C TIME STEP CONTROL.
  DT=DTBA
  IF(DT.GT.1.1D0*DTKOD.AND.DTKOD.NE.0.) DT=1.1D0*DTKOD
  IF(NCYC.EQ.2) DT=DT/10.
  IF (NCYC.EQ.1) DT=0.
  IF(DT.EQ.0.) GO TO 11
  NHAD=((TMUD-T)/DT-1.D-10)
  IF(NHAD.GE.10) GO TO 11
  DT=(TMUD-T)/DFLOAT(NHAD+1)
11  CONTINUE
  T=T+DT
  IF((NCYC/NCYCPR)*NCYCPR.NE.NCYC.AND.NCYC.GT.NCYCPR) GO TO 33
  PRINT 10, NCYC,T,DT,KDT
10  FORMAT(1X,'NCYC=',I4,3X,'T=',D11.4,3X,'DT=',D11.4,3X,'KDT=',I4)
33  CONTINUE
  DTBA=DTMUD
  KDT=0
  NERI=1
  IF (DABS(T-TMUD).LT.1.D-8) NERI=0
  CALL CYCEUL
1  (L,X,U,P,R,G,E,DU,DP,DRO,DG,DXSI,MIN,
2  US,PS,UIDOT,PIDOT,
*  FIMZ,ZMDOT,
3  TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ)
  CALL SAFAE
1  (L,X,U,P,R,G,E,DU,DP,DRO,DG,DXSI,MIN,
2  US,PS,UIDOT,PIDOT,
*  FIMZ,ZMDOT,
3  TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ)
  IF (NERI.NE.0) GO TO 2
  CALL PRINT
1  (L,X,U,P,R,G,E,DU,DP,DRO,DG,DXSI,MIN,
2  US,PS,UIDOT,PIDOT,
*  FIMZ,ZMDOT,
3  TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ)
  IF (DABS(T-TMUD).LT.1.D-8) TMUD=TMUD+DTMUD
2  CONTINUE
  DTKOD=DT
  IF (T.LT.TMAX-1.D-8) GO TO 1
  RETURN
END
SUBROUTINE NETUNM
IMPLICIT REAL*8(A-H,O-Z,$)
COMMON /AB/A(50)
EQUIVALENCE (L,A(1))
EQUIVALENCE (LL,A(2)),(T,A(3)),(DT,A(4)),(TMAX,A(5)),
1  (TMUD,A(6)),(DTMUD,A(7)),(JOB,A(8)),(NERI,A(9)),
2  (JJJ,A(10)),(KEYMON,A(11)),(NCYC,A(12))
EQUIVALENCE (COLELA,A(13))
EQUIVALENCE (LAGEUL,A(14))
EQUIVALENCE (KEYEK,A(16))
EQUIVALENCE (NCYCPR,A(17))
EQUIVALENCE (STAB,A(18)),(DTBA,A(19)),(DTKOD,A(20)),(KDT,A(21))
COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,PODET,ROODET
COMMON/DIFFUS/U2,P2,R02,ARW
COMMON /DRAW/GODELX,GODELY,UMIN,UMAX,PMIN,PMAX,ROMIN,ROMAX
1  ,XMIN,XMAX,SMIN,SMAX,IVERSA
COMMON /GAM/GAMA,NG,MU2,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11
1  ,G12,G13,G14,G15,G16,G17,G18,G19,G20
  REAL*8 NG
  REAL*8 MU2
  NAMELIST /IN/LIN,GAMA,DT, TMUD,DTMUD,TMAX,
1  GODELX,GODELY,UMIN,UMAX,PMIN,PMAX,ROMIN,ROMAX,
2  SMIN,SMAX,IVERSA,KEYMON,COLELA,STAB
3  ,LAGEUL,KEYEK
4  ,QDET,TC,RATE
C*****
  LIN=L
  LAGEUL=2
  NCYCPR=20

```

	KEYEK=1	HFL0145
	TMUD=0.	HFL0146
	DTMUD=0.2D0	HFL0147
	TMAX=2.0D0	HFL0148
	DT=2.5D-3	HFL0149
	GAMA=1.54D0	HFL0150
	KEYMON=1	HFL0151
	STAB=0.6D0	HFL0152
C	RATE=1.5D0	HFL0153
	GODELX=16.	HFL0154
	GODELY=20.	HFL0155
	IVERSA=100	HFL0156
	UMIN=0.	HFL0157
	UMAX= 3.D0	HFL0158
	PMIN=0.	HFL0159
	PMAX=1.D-3	HFL0160
	ROMIN=0.	HFL0161
	ROMAX=1.D-3	HFL0162
	SMIN=0.	HFL0163
	SMAX=PMAX/ROMAX**GAMA	HFL0164
	COLELA=0.	HFL0165
C	READ IN	HFL0166
C		HFL0167
	PRINT IN	HFL0168
C		HFL0169
	GG=2.*GAMA/(GAMA-1.)	HFL0170
	NG=GG	HFL0171
10	CONTINUE	HFL0172
	MU2=(GAMA-1.)/(GAMA+1.)	HFL0173
	G1=GAMA-1.	HFL0174
	G2=1.-MU2	HFL0175
	G3=2./(3.*GAMA-1.)	HFL0176
	G4=(GAMA+1.)/2.	HFL0177
	G5=0.5*(3.*GAMA-1.)/(GAMA+1.)	HFL0178
	G6=(GAMA+1.)/(2.*GAMA)	HFL0179
	G7=2./(GAMA-1.)	HFL0180
	G8=(GAMA-1.)/(2.*GAMA)	HFL0181
	G9=(GAMA+1.)/(4.*GAMA)	HFL0182
	G10=1./GAMA	HFL0183
	G11=(GAMA+1.)/4.	HFL0184
	G12=GAMA/(GAMA-1.)	HFL0185
	G13=0.5*(GAMA-3.)/(GAMA+1.)	HFL0186
	G14=0.5*(3.*GAMA-5.)/(GAMA+1.)	HFL0187
	G17=GAMA+1.	HFL0188
	GODELX=GODELX/2.54	HFL0189
	GODELY=GODELY/2.54	HFL0190
C	CALL NAMPLT(IVERSA)	HFL0191
C	CALL LIMIT(1000.)	HFL0192
C	CALL PLOT(0.,0.5,-3)	HFL0193
C	DATA FOR DIFFUSER ENTRY CONDITIONS. TEST III/2, REF.(M-1).	HFL0194
C	UNITS ARE IN M,K,MILISEC.	HFL0195
C	FH2 IS THE DIFFUSER ENTRY MOLAR FRACTION OF H ATOMS.	HFL0196
	FH2=0.091D0	HFL0197
	U2=2.3D0	HFL0198
	AMDOT=1.499D-5	HFL0199
	A2=1.D0*7.D0*0.0254**2	HFL0200
	R02=AMDOT/(A2*U2)	HFL0201
	TEMP0=1400.D0	HFL0202
	W2=7.27D0	HFL0203
	ARW=8.31441D-3/W2	HFL0204
	DELTAQ=435.783/2.D0	HFL0205
	QDET=FH2*DELTAQ/W2	HFL0206
	AA=U2/DSQRT(GAMA*ARW*TEMP0)	HFL0207
	RATE=1.4D0*1.D7*FH2/W2**2	HFL0208
	RATE=RATE*1.D2	HFL0209
	EM2=AA/DSQRT(1.-AA**2/G7)	HFL0210
	GOREM=(1.D0+EM2**2/G7)	HFL0211
	TRATIO=2.D0*(GAMA+1.D0)*EM2**2*GOREM/(1.D0+GAMA*EM2**2)**2	HFL0212
	HH0=GAMA*ARW*TEMP0/(GAMA-1.D0)	HFL0213
	HH1=HH0/TRATIO	HFL0214
	CHOKE=QDET/(HH1-HH0)	HFL0215
	TEMP2=TEMP0/GOREM	HFL0216


```

P2=ARW*RO2*TEMP2
RATIO=2.5D0/0.5D0
EMOUT=EM2*RATIO*((GAMA-1.D0)/2.D0)
DO 250 I=1,100
EMOUT1=EMOUT
GOREM=RATIO*EMOUT*(1.D0+0.5D0*(GAMA-1.D0)*EM2**2)**(0.5D0/MU2)/EM2
GOREM=GOREM**((2.D0*MU2)
EMOUT=DSQRT((2.D0/(GAMA-1.D0))*(GOREM-1.D0))
DM=DABS(EMOUT-EMOUT1)
IF(DM.LT.1.D-9) GO TO 251
250 CONTINUE
CALL SOF(251)
251 CONTINUE
PRINT 201
201 FORMAT(/1X,'DIFFUSER ENTRY DATA')
PRINT 202,U2,P2,RO2,FH2
202 FORMAT(1X,'U2,P2,RO2,FH2=',4D16.5)
PRINT 203,AMDOT,W2,TEMP0,TEMP2,EM2
203 FORMAT(1X,'AMDOT,W2,TEMP0,TEMP2,EM2=',5D16.5)
PRINT 204,RATE,QDET,HH0,HH1,CHOKE
204 FORMAT(1X,'RATE,QDET,HH0,HH1,CHOKE=',5D16.5/)
PRINT 205,RATIO,EMOUT
205 FORMAT(1X,'EXIT AREA RATIO AND MACH NUMBER RATIO,EMOUT=',2D16.5)
RETURN
END
SUBROUTINE BEGIN
1 (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,
2 US,PS,UIDOT,PIDOT,
* FIMZ,ZMDOT,
3 TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ)
IMPLICIT REAL*8(A-H,O-Z,$)
DIMENSION X(L),U(L),P(L),RO(L),G(L),E(L),DU(L),DP(L),DRO(L),
1 DG(L),DXSI(L),MIN(L),
2 US(L),PS(L),UIDOT(L),PIDOT(L)
3 ,TENA(L),FIRO(L),FIM(L),FIE(L)
4 ,GIP(L),VOL(L),Z(L),DZ(L)
5 ,FIMZ(L),ZMDOT(L)
COMMON /AB/A(50)
COMMON /GAM/GAMA,NG,MU2,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11
1 ,G12,G13,G14,G15,G16,G17,G18,G19,G20
REAL*8 NG
REAL*8 MU2
EQUIVALENCE (LL,A(2))
EQUIVALENCE (LAGEUL,A(14))
EQUIVALENCE (UGAL,A(15))
EQUIVALENCE (STAB,A(18)),(DTBA,A(19)),(DTKOD,A(20)),(KDT,A(21))
COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,P0DET,ROODET
COMMON /DRAW/GODELX,GODELY,UMIN,UMAX,PMIN,PMAX,ROMIN,ROMAX
1 ,XMIN,XMAX,SMIN,SMAX,IVERSA
C*****
DTBA=0.
DTKOD=0.
KDT=0
P0=1.D-7
RH00=1.D-7
P1=0.1
P1=4.
RH01=0.125
RH01=4.
UGAL=0.
U0=1.08D0
U1=0.
U0=U0-UGAL
U1=U1-UGAL
UMIN=UMIN-UGAL
UMAX=UMAX-UGAL
X0=0.625D0
X1=3.125D0
XMIN=X0
XMAX=X1
DX=(X1-X0)/(L-2.)
DO 1 I=2,L

```

	X(I)=X0+(I-2.)*DX	HFL0289
1	CONTINUE	HFL0290
	X(L)=X1	HFL0291
	XD=1.D10	HFL0292
	DO 2 I=2,LL	HFL0293
	U(I)=U0/X(I)	HFL0294
	P(I)=P0	HFL0295
	RO(I)=RH00	HFL0296
	Z(I)=0.	HFL0297
	IF (X(I)-XD.LT.-1.D-8) GO TO 21	HFL0298
	U(I)=U1	HFL0299
	P(I)=P1	HFL0300
	RO(I)=RH01	HFL0301
	Z(I)=1.D0	HFL0302
21	CONTINUE	HFL0303
	GO TO (31,32), LAGEUL	HFL0304
31	CONTINUE	HFL0305
	E(I)=P(I)/((GAMA-1.)*RO(I))+0.5*U(I)**2+Z(I)*QDET	HFL0306
	GO TO 30	HFL0307
32	CONTINUE	HFL0308
	E(I)=P(I)/(GAMA-1.)+0.5*RO(I)*U(I)**2+Z(I)*RO(I)*QDET	HFL0309
30	CONTINUE	HFL0310
	G(I)=DSQRT(GAMA*P(I)*RO(I))	HFL0311
2	CONTINUE	HFL0312
	DO 3 I=2,LL	HFL0313
	DXSI(I)=(X(I+1)-X(I))*RO(I)	HFL0314
	TENA(I)=RO(I)*U(I)	HFL0315
	VOL(I)=(X(I+1)-X(I))*(X(I+1)+X(I))/2.D0	HFL0316
3	CONTINUE	HFL0317
	RETURN	HFL0318
	END	HFL0319
	DOUBLE PRECISION FUNCTION RATIO(X)	HFL0320
	IMPLICIT REAL*8(A-H,O-Z,\$)	HFL0321
	IF(X.LE.1.D-8)RATIO=0.	HFL0322
	IF(X.LE.1.D-8)RETURN	HFL0323
	RATIO=1.D0/X	HFL0324
	RETURN	HFL0325
	END	HFL0326
	DOUBLE PRECISION FUNCTION CROSS(X)	HFL0327
	IMPLICIT REAL*8(A-H,O-Z,\$)	HFL0328
	CROSS=X	HFL0329
	RETURN	HFL0330
	END	HFL0331
	SUBROUTINE CYCEUL	HFL0332
1	(L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,	HFL0333
2	US,PS,UIDOT,PIDOT,	HFL0334
*	FIMZ,ZMDOT,	HFL0335
3	TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ)	HFL0336
	IMPLICIT REAL*8(A-H,O-Z,\$)	HFL0337
	DIMENSION X(L),U(L),P(L),RO(L),G(L),E(L),DU(L),DP(L),DRO(L),	HFL0338
1	DG(L),DXSI(L),MIN(L),	HFL0339
2	US(L),PS(L),UIDOT(L),PIDOT(L)	HFL0340
3	,TENA(L),FIRO(L),FIM(L),FIE(L)	HFL0341
4	,GIP(L),VOL(L),Z(L),DZ(L)	HFL0342
5	,FIMZ(L),ZMDOT(L)	HFL0343
	COMMON /AB/A(50)	HFL0344
	EQUIVALENCE (LL,A(2)),(T,A(3)),(DT,A(4)),(COLELA,A(13))	HFL0345
	EQUIVALENCE (KEYEK,A(16))	HFL0346
	EQUIVALENCE (STAB,A(18)),(DTBA,A(19)),(DTKOD,A(20)),(KDT,A(21))	HFL0347
	COMMON /GAM/GAMA,NG,MU2,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11	HFL0348
1	,G12,G13,G14,G15,G16,G17,G18,G19,G20	HFL0349
	REAL*8 NG	HFL0350
	REAL*8 MU2	HFL0351
	COMMON /TOT/AMTOT,ETOT,EKTOT,EPTOT,TENTOT	HFL0352
	COMMON /AZOV/ISAF,NORIMN,USAF,PSAF,ROSAF,GSAF,ESAF,DPSAF	HFL0353
1	,DXSIL,DXSIR	HFL0354
	LOGICAL NORIMN	HFL0355
	COMMON /STEP0/UL,PL,ROL,GL,UR,PR,ROR,GR,USTAR,PSTAR,	HFL0356
1	RSTARL,RSTARR,GSTARL,GSTARR,WL,WR,	HFL0357
2	CL,CR,CSTARL,CSTARR,UW(6)	HFL0358
3	,ZL,ZR,ZSTARL,ZSTARR,NFLUX,HELEML,HELEMR	HFL0359
	LOGICAL HELEML,HELEMR	HFL0360

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COMMON /STEP1/DUIDT,DPIDT,DGIDTL,DGIDTR,DRIDTL,DRIDTR      HFL0361
2 ,ASTARL,ASTARR                                             HFL0362
3 ,RAT,SH                                                    HFL0363
COMMON /GRADS/DUDXIL,DPDXIL,DGDIXIL,DRDXIL,                HFL0364
1 DUDXIR,DPDXIR,DGDIXIR,DRDXIR                             HFL0365
COMMON /FI/FIH1,FIH2,FIH3,UXN,PXN,GXN,ROXN                 HFL0366
1 ,GIH                                                       HFL0367
2 ,FIH4,ZMDOTL,ZMDOTR                                       HFL0368
COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,P0DET,RO0DET HFL0369
C DATA KOTZ/7777777777B/                                     HFL0370
C*****HFL0371
TN=T                                                         HFL0372
DT2=DT/2.                                                    HFL0373
DO 3 I=1,L                                                    HFL0374
C MINO=MIN(I).AND.KOTZ                                         HFL0375
C MIN(I)=SHIFT(MINO,30)                                         HFL0376
3 CONTINUE                                                    HFL0377
UXN=0.                                                         HFL0378
PXN=0.                                                         HFL0379
GXN=0.                                                         HFL0380
ZN=0.                                                         HFL0381
ROXN=0.                                                       HFL0382
DO 1 I=2,L                                                    HFL0383
IM=I-1                                                        HFL0384
UXNM=UXN                                                       HFL0385
PXNM=PXN                                                       HFL0386
GXNM=GXN                                                       HFL0387
ROXNM=ROXN                                                     HFL0388
ZNM=ZN                                                         HFL0389
UL=U(IM)+0.5*DU(IM)                                           HFL0390
PL=P(IM)+0.5*DP(IM)                                           HFL0391
ROL=RO(IM)+0.5*DRO(IM)                                         HFL0392
GL=G(IM)+0.5*DG(IM)                                           HFL0393
CL=GL/ROL                                                      HFL0394
ZL=Z(IM)+0.5*DZ(IM)                                           HFL0395
UR=U(I)-0.5*DU(I)                                             HFL0396
PR=P(I)-0.5*DP(I)                                             HFL0397
GR=G(I)-0.5*DG(I)                                             HFL0398
ROR=RO(I)-0.5*DRO(I)                                          HFL0399
CR=GR/ROR                                                      HFL0400
ZR=Z(I)-0.5*DZ(I)                                             HFL0401
CALL RIEMAN(L,I,MIN)                                           HFL0402
DUDXIL=DU(IM)/DXSI(IM)                                         HFL0403
DPDXIL=DP(IM)/DXSI(IM)                                         HFL0404
DGDIXIL=DG(IM)/DXSI(IM)                                         HFL0405
DRDXIL=DRO(IM)/DXSI(IM)                                         HFL0406
DUDXIR=DU(I)/DXSI(I)                                           HFL0407
DPDXIR=DP(I)/DXSI(I)                                           HFL0408
DGDIXIR=DG(I)/DXSI(I)                                           HFL0409
DRDXIR=DRO(I)/DXSI(I)                                           HFL0410
SH=CROSS(X(I))                                                 HFL0411
RAT=RATIO(X(I))                                                 HFL0412
CALL MAGA(L,I,MIN)                                             HFL0413
US(I)=USTAR                                                    HFL0414
PS(I)=PSTAR                                                    HFL0415
UIDOT(I)=DUIDT                                                  HFL0416
PIDOT(I)=DPIDT                                                  HFL0417
CALL FLUXE1(L,I,MIN)                                           HFL0418
CALL FLUXE2(L,I,MIN)                                           HFL0419
FIRO(I)=FIH1                                                    HFL0420
FIM (I)=FIH2                                                    HFL0421
FIE (I)=FIH3                                                    HFL0422
GIP(I)=GIH                                                      HFL0423
FIMZ(I)=FIH4                                                    HFL0424
DU(IM)=UXN-UXNM                                                 HFL0425
DP(IM)=PXN-PXNM                                                 HFL0426
DG(IM)=GXN-GXNM                                                 HFL0427
DRO(IM)=ROXN-ROXNM                                              HFL0428
1 CONTINUE                                                    HFL0429
AMTOT=0.                                                         HFL0430
ETOT=0.                                                         HFL0431
EKTOT=0.                                                         HFL0432

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EPTOT=0.	HFL0433
TENTOT=0.	HFL0434
FI1=FIRO(2)	HFL0435
FI2=FIM(2)	HFL0436
FI4=FIMZ(2)	HFL0437
GI2=GIP(2)	HFL0438
SH=CROSS(X(2))	HFL0439
DO 2 I=2,LL	HFL0440
IP=I+1	HFL0441
FIM1=FI1	HFL0442
FIM2=FI2	HFL0443
FIM4=FI4	HFL0444
GIM2=GI2	HFL0445
SHM=SH	HFL0446
GI2=GIP(IP)	HFL0447
SH=CROSS(X(IP))	HFL0448
DVOL=VOL(I)	HFL0449
FI1=FIRO(IP)	HFL0450
FI2=FIM(IP)	HFL0451
FI4=FIMZ(IP)	HFL0452
ZKODM=Z(I)*RO(I)	HFL0453
DX=X(IP)-X(I)	HFL0454
RO(I)=RO(I)-DT/DVOL*(SH*FI1-SHM*FIM1)	HFL0455
TENA(I)=TENA(I)-DT/DVOL*(SH*FI2-SHM*FIM2)-DT/DX*(GI2-GIM2)	HFL0456
U(I)=TENA(I)/RO(I)	HFL0457
IF(QDET.EQ.0.) GO TO 2	HFL0458
Z(I)=(ZKODM-(DT/DVOL)*(SH*FI4-SHM*FIM4))/RO(I)	HFL0459
DZZ1=Z(I)-1.D0	HFL0460
IF(DZZ1.LT.1.D-6.AND.Z(I).GE.0.) GO TO 7350	HFL0461
IF(DZZ1.LT.0.) GO TO 7352	HFL0462
Z(I)=1.D0	HFL0463
IF(DZZ1.LT.0.2D0) GO TO 7350	HFL0464
7352 CONTINUE	HFL0465
IF(Z(I).GT.0.) GO TO 7353	HFL0466
Z(I)=0.	HFL0467
IF(DABS(Z(I)).LT.0.2D0) GO TO 7350	HFL0468
7353 CONTINUE	HFL0469
PRINT 7351,I,Z(I),P(I),RO(I),E(I),U(I),ZMDOT(I)	HFL0470
7351 FORMAT(/1X,'CYCEUL. I,Z,P,RO,E,U,ZMDOT=',I5,6D15.5/)	HFL0471
CALL SOF(7350)	HFL0472
7350 CONTINUE	HFL0473
IF(Z(I).GT..1D1) Z(I)=.1D1	HFL0474
2 CONTINUE	HFL0475
IF(COLELA.EQ.0.) GO TO 201	HFL0476
CALL DCOLE(L,X,U,DU,MIN,1)	HFL0477
CALL DCOLE(L,X,RO,DRO,MIN,4)	HFL0478
201 CONTINUE	HFL0479
CALL BDOK1(L,X,U,DU,MIN,1)	HFL0480
CALL BDOK1(L,X,RO,DRO,MIN,4)	HFL0481
FI3=FIE(2)	HFL0482
SH=CROSS(X(2))	HFL0483
DO 6 I=2,LL	HFL0484
IP=I+1	HFL0485
SHM=SH	HFL0486
SH=CROSS(X(IP))	HFL0487
DVOL=VOL(I)	HFL0488
FIM3=FI3	HFL0489
FI3=FIE(IP)	HFL0490
DX=X(IP)-X(I)	HFL0491
E(I)=E(I)-DT/DVOL*(SH*FI3-SHM*FIM3)	HFL0492
C UAV=U(I)	HFL0493
C	HFL0494
ROAV=RO(I)	HFL0495
C	HFL0496
EP=E(I)-0.5*ROAV*UAV**2	HFL0497
IF(QDET.EQ.0.) GO TO 64	HFL0498
TI=P(I)	HFL0499
DZZ=-RATE*DT*(RO(I)*Z(I))**2	HFL0500
Z(I)=Z(I)+DZZ	HFL0501
IF(Z(I).LT.0.) Z(I)=0.	HFL0502
IF(Z(I).LT.0.01) Z(I)=0.	HFL0503
	HFL0504


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64 EP=EP-Z(I)*RO(I)*QDET HFL0505
CONTINUE HFL0506
GO TO (61,62), KEYEK HFL0507
61 CONTINUE HFL0508
GO TO 60 HFL0509
62 CONTINUE HFL0510
DEK=(ROAV*DU(I)**2+2.*DRO(I)*DU(I)*UAV)/24. HFL0511
EP=EP-DEK HFL0512
GO TO 60 HFL0513
60 CONTINUE HFL0514
IF(EP.LE.0.) GO TO 7001 HFL0515
P(I)=G1*EP HFL0516
G(I)=DSQRT(GAMA*P(I)*RO(I)) HFL0517
DM=RO(I)*DX HFL0518
DXSI(I)=DM HFL0519
DM=RO(I)*DVOL HFL0520
ETOT=ETOT+E(I)*DVOL HFL0521
EPTOT=EPTOT+EP*DVOL HFL0522
AMTOT=AMTOT+DM HFL0523
ETOT=ETOT+E(I)*DX HFL0524
EPTOT=EPTOT+EP*DX HFL0525
TENTOT=TENTOT+DX*TENA(I) HFL0526
UPC=DABS(U(I))+G(I)/RO(I) HFL0527
DTI=STAB*DX/UPC HFL0528
IF(DTI.GT.DTBA) GO TO 69 HFL0529
DTBA=DTI HFL0530
KDT=I HFL0531
69 CONTINUE HFL0532
6 CONTINUE HFL0533
CALL DCOLE(L,X,Z,DZ,MIN,5) HFL0534
IF(COLELA.EQ.0.) GO TO 601 HFL0535
CALL DCOLE(L,X,P,DP,MIN,2) HFL0536
CALL DCOLE(L,X,G,DG,MIN,3) HFL0537
601 CONTINUE HFL0538
CALL BDOK1(L,X,P,DP,MIN,2) HFL0539
CALL BDOK1(L,X,G,DG,MIN,3) HFL0540
CALL BDOK1(L,X,Z,DZ,MIN,5) HFL0541
EKTOT=ETOT-EPTOT HFL0542
RETURN HFL0543
7001 CONTINUE HFL0544
PRINT 7101, I,ROAV,UAV,DRO(I),DU(I),E(I),DEK,EP,KEYEK HFL0545
7101 FORMAT(/I,X,'FROM CYCEUL. NEGATIVE EP. IN CELL I=',I6// HFL0546
1 1X,'ROAV,UAV,DRO(I),DU(I)=' ,4D18.8// HFL0547
2 1X,'E(I),DEK,EP,KEYEK=' ,3D18.8,I10// HFL0548
CALL SOF(7001) HFL0549
RETURN HFL0550
END HFL0551
SUBROUTINE SAFAE HFL0552
1 (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN, HFL0553
2 US,PS,UIDOT,PIDOT, HFL0554
* FIMZ,ZMDOT, HFL0555
3 TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ) HFL0556
IMPLICIT REAL*8(A-H,O-Z,$) HFL0557
DIMENSION X(L),U(L),P(L),RO(L),G(L),E(L),DU(L),DP(L),DRO(L), HFL0558
1 DG(L),DXSI(L),MIN(L), HFL0559
2 US(L),PS(L),UIDOT(L),PIDOT(L) HFL0560
3 ,TENA(L),FIRO(L),FIM(L),FIE(L) HFL0561
4 ,GIP(L),VOL(L),Z(L),DZ(L) HFL0562
5 ,FIMZ(L),ZMDOT(L) HFL0563
COMMON /AB/A(50) HFL0564
EQUIVALENCE (LL,A(2)),(T,A(3)),(DT,A(4)),(NCYC,A(12)) HFL0565
COMMON /GAM/GAMA,NG,MU2,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11 HFL0566
1 ,G12,G13,G14,G15,G16,G17,G18,G19,G20 HFL0567
REAL*8 NG HFL0568
REAL*8 MU2 HFL0569
COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,PODET,ROODET HFL0570
COMMON/DIFFUS/U2,P2,RO2,ARW HFL0571
C***** HFL0572
TN=T HFL0573
C HFL0574
C INFLOW B.C. AT I=2 HFL0575
C HFL0576

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      U(1)=U2                                HFL0577
      P(1)=P2                                HFL0578
      RO(1)=RO2                               HFL0579
      G(1)=DSQRT(GAMA*P(1)*RO(1))           HFL0580
      Z(1)=1.D0                              HFL0581
      DU(1)=0.                               HFL0582
      DP(1)=0.                               HFL0583
      DG(1)=0.                               HFL0584
      DRO(1)=0.                              HFL0585
      DXSI(1)=DXSI(2)                        HFL0586
C                                           HFL0587
C OUTFLOW B.C. AT I=L                       HFL0588
C                                           HFL0589
      U(L)=U(LL)                             HFL0590
      P(L)=P(LL)                             HFL0591
      RO(L)=RO(LL)                           HFL0592
      G(L)=DSQRT(GAMA*P(L)*RO(L))           HFL0593
      DU(L)=0.                               HFL0594
      DP(L)=0.                               HFL0595
      DG(L)=0.                               HFL0596
      DRO(L)=0.                              HFL0597
      DXSI(L)=DXSI(LL)                      HFL0598
C                                           HFL0599
      RETURN                                  HFL0600
      END                                     HFL0601
-----
SUBROUTINE BDOK1(L,X,V,DV,MIN,NV)           HFL0602
IMPLICIT REAL*3(A-H,O-Z,$)                 HFL0603
DIMENSION X(L),V(L),DV(L),MIN(L)           HFL0604
COMMON /AB/A(50)                            HFL0605
EQUIVALENCE (LL,A(2)),(KEYMON,A(11))       HFL0606
COMMON /DRAW/GODELX,GODELY,UMIN,UMAX,PMIN,PMAX,ROMIN,ROMAX HFL0607
1      ,XMIN,XMAX,SMIN,SMAX,IVERSA          HFL0608
COMMON /MONIT/NC14(4),CASEAV(4),NF16(6),    HFL0609
1      NMONU(4),NMONP(4),NMONG(4),NMONRO(4),NMONZ(4) HFL0610
DIMENSION NMONV(4,5)                       HFL0611
EQUIVALENCE (NMONV(1,1),NMONU(1))          HFL0612
C DIMENSION NAMEV(5)                        HFL0613
C DATA NAMEV/1HU,1HP,1HG,2HRO,1HZ/        HFL0614
DATA EPS/1.D-15/                           HFL0615
C*****                                     HFL0616
C NV=0                                       HFL0617
C DO 10 N=1,5                               HFL0618
C IF (NAME.EQ.NAMEV(N))NV=N                 HFL0619
C10 CONTINUE                                HFL0620
1 GO TO (1,2,3,4,5), NV                     HFL0621
1 AMIDA=(UMAX-UMIN)**2                       HFL0622
GO TO 9                                       HFL0623
2 AMIDA=(PMAX-PMIN)**2                       HFL0624
GO TO 9                                       HFL0625
3 AMIDA=((UMAX-UMIN)*(ROMAX-ROMIN))**2      HFL0626
GO TO 9                                       HFL0627
4 AMIDA=(ROMAX-ROMIN)**2                     HFL0628
GO TO 9                                       HFL0629
5 AMIDA=1.D0                                HFL0630
GO TO 9                                       HFL0631
9 CONTINUE                                  HFL0632
AMIDA=AMIDA*EPS**2                           HFL0633
AMIDA=EPS                                    HFL0634
DO 29 I=2,LL                                HFL0635
ICAT=0                                       HFL0636
VLEFT=V(I)-0.5D0*DV(I)                     HFL0637
VRIGHT=V(I)+0.5D0*DV(I)                    HFL0638
VM=V(I-1)                                   HFL0639
VP=V(I+1)                                   HFL0640
SIGN=(VP-V(I))*(V(I)-VM)                   HFL0641
IF(SIGN.GT.-AMIDA) GO TO 22                 HFL0642
21 DV(I)=0.                                  HFL0643
ICAT=1                                       HFL0644
GO TO 20                                    HFL0645
22 CONTINUE                                 HFL0646
SIGN=(VP-VM)*DV(I)                         HFL0647
IF(SIGN.GT.-AMIDA) GO TO 24                 HFL0648

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23  DV(I)=0.5D0*(VP-VM)                                HFL0649
    VLEFT=V(I)-0.5D0*DV(I)                             HFL0650
    VRIGHT=V(I)+0.5D0*DV(I)                             HFL0651
    ICAT=2                                                HFL0652
24  SIGN=(VLEFT-VM)*DV(I)                               HFL0653
    IF(SIGN.GT.-AMIDA) GO TO 26                          HFL0654
25  VLEFT=VM                                             HFL0655
    VRIGHT=2.D0*V(I)-VLEFT                             HFL0656
    DV(I)=VRIGHT-VLEFT                                  HFL0657
    ICAT=3                                                HFL0658
26  SIGN=(VP-VRIGHT)*DV(I)                             HFL0659
    IF (SIGN.GT.-AMIDA) GO TO 28                        HFL0660
27  VRIGHT=VP                                           HFL0661
    VLEFT=2.D0*V(I)-VRIGHT                             HFL0662
    DV(I)=VRIGHT-VLEFT                                  HFL0663
    ICAT=3                                                HFL0664
28  IF(DABS(DV(I)).LE.0.5D0*DABS(VP-VM)) GO TO 31      HFL0665
30  DV(I)=0.5D0*(VP-VM)                                HFL0666
    ICAT=4                                                HFL0667
31  CONTINUE                                           HFL0668
20  CONTINUE                                           HFL0669
    IF (DV(I)**2.GT.AMIDA) GO TO 40                     HFL0670
    DV(I)=0.                                            HFL0671
40  CONTINUE                                           HFL0672
C   IF (ICAT.GT.0) NMONV(ICAT,NV)=NMONV(ICAT,NV)+1     HFL0673
C   IBYTE0=5                                             HFL0674
C   MIN(I)=MIN(I).OR.SHIFT(ICAT,(NV+IBYTE0-2)*3)       HFL0675
29  CONTINUE                                           HFL0676
    RETURN                                              HFL0677
    END                                                HFL0678
-----
SUBROUTINE DCOLE(L,X,V,DV,MIN,NV)                      HFL0679
IMPLICIT REAL*8(A-H,O-Z,$)                            HFL0680
DIMENSION X(L),V(L),DV(L),MIN(L)                      HFL0681
COMMON /AB/A(50)                                       HFL0682
EQUIVALENCE (LL,A(2))                                HFL0683
C*****HFL0684
DO 1 I=2,LL                                           HFL0685
  IM=I-1                                              HFL0686
  IP=I+1                                              HFL0687
  DV(I)=0.5*(V(IP)-V(IM))                            HFL0688
1  CONTINUE                                           HFL0689
  RETURN                                              HFL0690
  END                                                HFL0691
-----
SUBROUTINE PRINT                                       HFL0692
1      (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,        HFL0693
2      US,PS,UIDOT,PIDOT,                            HFL0694
*      FIMZ,ZMDOT,                                    HFL0695
3      TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ)               HFL0696
IMPLICIT REAL*8(A-H,O-Z,$)                            HFL0697
DIMENSION X(L),U(L),P(L),RO(L),G(L),E(L),DU(L),DP(L),DRO(L), HFL0698
1      DG(L),DXSI(L),MIN(L),                          HFL0699
2      US(L),PS(L),UIDOT(L),PIDOT(L)                 HFL0700
3      ,TENA(L),FIRO(L),FIM(L),FIE(L)                 HFL0701
4      ,GIP(L),VOL(L),Z(L),DZ(L)                     HFL0702
5      ,FIMZ(L),ZMDOT(L)                             HFL0703
COMMON /TOT/AMTOT,ETOT,EKTOT,EPTOT,TENTOT            HFL0704
COMMON /STEPO/UL,PL,ROL,GL,UR,PR,ROR,GR,USTAR,PSTAR, HFL0705
1      RSTARL,RSTARR,GSTARL,GSTARR,WL,WR,             HFL0706
2      CL,CR,CSTARL,CSTARR,UW(6)                     HFL0707
3      ,ZL,ZR,ZSTARL,ZSTARR,NFLUX,HELEML,HELEMR       HFL0708
LOGICAL HELEML,HELEMR                                HFL0709
COMMON /AB/A(50)                                       HFL0710
EQUIVALENCE (LL,A(2)),(T,A(3)),(NCYC,A(12)),(DT,A(4)) HFL0711
EQUIVALENCE (UGAL,A(15))                             HFL0712
COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,P0DET,RO0DET HFL0713
COMMON/DIFFUS/U2,P2,RO2,ARW                          HFL0714
COMMON /GAM/GAMA,NG,MU2,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11 HFL0715
1      ,G12,G13,G14,G15,G16,G17,G18,G19,G20          HFL0716
REAL*8 NG                                             HFL0717
REAL*8 MU2                                            HFL0718
COMMON /MONIT/NC14(4),CASEAV(4),NF16(6),             HFL0719
1      NMONU(4),NMONP(4),NMONG(4),NMONRO(4),NMONZ(4)  HFL0720

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DIMENSION CASAV1(4)
LOGICAL FULLPR
COMMON /PRNT/ROX,PX,UX,ZX
C*****
FULLPR=.TRUE.
PRINT 1
1 FORMAT(1H1)
PRINT 2, T,DT,NCYC
2 FORMAT(1X,10X,'RESULTS AT T=',D11.5,5X,'DT=',D11.5,5X,'NCYC=',
1 I5//)
PRINT 3, AMTOT,ETOT,EKTOT,EPTOT,TENTOT
3 FORMAT(1X,'AMTOT=',D20.14,2X,'ETOT,EKTOT,EPTOT=',3D22.14/
1 1X,'TENTOT=',D21.14//)
44 FORMAT(1X,' I',' X',' U',' P','
1 ' RO',' G',' Z','
2 ' DU',' DP',' DRO','
3 ' DG',' DZ')
44 1 ' ZMDOT',' FIMZ',' AMDOT','
2 ' AMDOTN',' TEMP',' ENTALP','
3 ' AMACH',' ENTRO')
5 FORMAT(1X)
IF (UGAL.NE.0.) PRINT 6, UGAL
6 FORMAT(/1X,'INITIAL VELOCITY CORRESPONDS TO UGAL=',D15.6/)
DO 10 I=1,L
IF (MOD(I,10).NE.1) GO TO 11
PRINT 5
PRINT 4
PRINT 44
PRINT 5
11 CONTINUE
PRINT 12,I,X(I),U(I),P(I),RO(I),G(I),Z(I),DU(I),DP(I),DRO(I),
1 DG(I),DZ(I))
12 FORMAT(1X,I3,6D12.5,5D11.4)
ENTRO=P(I)/RO(I)**GAMA
IF(.NOT.FULLPR) GO TO 131
IF(I.EQ.1) GO TO 131
IM=I-1
UL=U(IM)+0.5*DU(IM)
PL=P(IM)+0.5*DP(IM)
ROL=RO(IM)+0.5*DRO(IM)
GL=G(IM)+0.5*DG(IM)
CL=GL/ROL
ZL=Z(IM)+0.5*DZ(IM)
UR=U(I)-0.5*DU(I)
PR=P(I)-0.5*DP(I)
GR=G(I)-0.5*DG(I)
ROR=RO(I)-0.5*DRO(I)
CR=GR/ROR
ZR=Z(I)-0.5*DZ(I)
CALL RIEMAN(L,I,MIN)
CALL FLUXE1(L,I,MIN)
XI=X(I)
IF(I.EQ.L) GO TO 222
UX=U(I)
PX=P(I)
ROX=RO(I)
ZX=Z(I)
IP=I+1
XI=0.5D0*(X(I)+X(IP))
222 CONTINUE
AMACH=UX/DSQRT(GAMA*PX/ROX)
AMDOT=ROX*UX*CROSS(XI)
IF(I.EQ.2)AMDOT0=AMDOT
AMDOTN=AMDOT/AMDOT0
ENTALP=(GAMA/(GAMA-1.D0))*PX/ROX+0.5D0*UX**2
TEMP=PX/(ROX*ARW)
PRINT 13,US(I),PS(I),
1 ZMDOT(I),FIMZ(I),AMDOT,AMDOTN,TEMP,ENTALP,AMACH,ENTRO
13 FORMAT(4X,12X,5D12.5,6D11.4)
131 CONTINUE
10 CONTINUE

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HFL0721
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HFL0791
HFL0792


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C  JOB STATISTICS                                     HFL0793
C  DO 40 I=1,4                                         HFL0794
C  CASAV1(I)=0.                                         HFL0795
C  IF (NC14(I).NE.0) CASAV1(I)=CASEAV(I)/NC14(I)       HFL0796
C40  CONTINUE                                           HFL0797
C  PRINT 30                                             HFL0798
C30  FORMAT(///1X,10(1H*),3X,'JOB STATISTICS',3X,10(1H*)//) HFL0799
C  PRINT 31,(NC14(I),I=1,4)                             HFL0800
C31  FORMAT(1X,'NO. OF VARIOUS CASES IN RIEMAN SOLVER  NC14(NCASE)=' ,
C  1  4I10)                                             HFL0801
C  PRINT 301,(CASAV1(I),I=1,4)                           HFL0802
C301  FORMAT(/1X,'AVERAGE NUMBER OF ITERATIONS IN RIEMAN SOLVER',
C  1  1X,' CASAV1(NCASE)=' ,4(F6.2,4X))                HFL0803
C  PRINT 32,(NF16(I),I=1,6)                             HFL0804
C32  FORMAT(/1X,'NO. OF VARIOUS FLUX CASES  NF16(NFLUX)=' ,6I10) HFL0805
C  ICAT0=4                                              HFL0806
C  PRINT 33,(NMONU(I),I=1,ICAT0),(NMONP(I),I=1,ICAT0),
C  1  (NMONG(I),I=1,ICAT0),(NMONRO(I),I=1,ICAT0)       HFL0807
C33  FORMAT(/1X,'NO. OF MONOTONICITY INTERVENTIONS FOR EACH VAR.',
C  1  1X,'IN EACH CATEGORY.'//                         HFL0808
C  1  1X,'NMONU (ICAT)=' ,4I10/                       HFL0809
C  1  1X,'NMONP (ICAT)=' ,4I10/                       HFL0810
C  1  1X,'NMONG (ICAT)=' ,4I10/                       HFL0811
C  1  1X,'NMONRO (ICAT)=' ,4I10/                      HFL0812
C  RETURN                                              HFL0813
C  END                                                HFL0814
C  SUBROUTINE SOF(ISTOP)                                HFL0815
C  IMPLICIT REAL*8(A-H,O-Z,$)                         HFL0816
C  PRINT 1, ISTOP                                       HFL0817
C  1  FORMAT(1X,3H***,3X,'SOF',I6,3X,3H***/)          HFL0818
C  XX=-1.D0                                             HFL0819
C  YY=DSQRT(XX)                                         HFL0820
C  CALL SYSTEM(51,16H SUBROUTINE TREE)                HFL0821
C  STOP                                                 HFL0822
C  END                                                 HFL0823
C  SUBROUTINE RIEMAN(L,I,MIN)                          HFL0824
C  IMPLICIT REAL*8(A-H,O-Z,$)                         HFL0825
C  DIMENSION MIN(L)                                    HFL0826
C  COMMON /STEP0/UL,PL,ROL,GL,UR,PR,ROR,GR,USTAR,PSTAR,
C  1  RSTARL,RSTARR,GSTARL,GSTARR,WL,WR,              HFL0827
C  2  CL,CR,CSTARL,CSTARR,UW(6)                      HFL0828
C  3  ,ZL,ZR,ZSTARL,ZSTARR,NFLUX,HELEML,HELEMR       HFL0829
C  LOGICAL HELEML,HELEMR                             HFL0830
C  COMMON /STEP1/DUIDT,DPIDT,DGIDTL,DGIDTR,DRIDTL,DRIDTR
C  2  ,ASTARL,ASTARR                                  HFL0831
C  3  ,RAT,SH                                           HFL0832
C  COMMON /DRAW/GODELX,GODELY,UMIN,UMAX,PMIN,PMAX,ROMIN,ROMAX
C  1  ,XMIN,XMAX,SMIN,SMAX,IVERSA                    HFL0833
C  COMMON /GAM/GAMA,NG,MU2,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11
C  1  ,G12,G13,G14,G15,G16,G17,G18,G19,G20           HFL0834
C  REAL*8 NG                                            HFL0835
C  REAL*8 MU2                                           HFL0836
C  COMMON /AB/A(50)                                    HFL0837
C  COMMON /MONIT/NC14(4),CASEAV(4),NF16(6),           HFL0838
C  1  NMONU(4),NMONP(4),NMONG(4),NMONRO(4),NMONZ(4)  HFL0839
C *****                                             HFL0840
C  DATA NMAX/63/                                       HFL0841
C  DATA EPS/1.D-8/                                    HFL0842
C *****                                             HFL0843
C  IF(PL.GT.0..AND.PR.GT.0.) GO TO 7201               HFL0844
C  PRINT 7211,I,PL,PR                                  HFL0845
C  7211  FORMAT(' FROM RIEMAN. I,PL,PR=' ,I6,2D16.6/) HFL0846
C  CALL SOF(7654)                                       HFL0847
C  7201  CONTINUE                                       HFL0848
C  UW(6)=1.D20                                         HFL0849
C  WL=0.                                                HFL0850
C  WR=0.                                                HFL0851
C  ZETAL=PL*G8                                         HFL0852
C  ZETAR=PR*G8                                         HFL0853
C  CLG=CL/GAMA                                         HFL0854
C  CRG=CR/GAMA                                         HFL0855
C  ZSTARL=ZL                                           HFL0856

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      ZSTARR=ZR
      IF (ZETAL.LT.ZETAR) GO TO 102
C LEFT PRESSURE IS HIGHER
101 CONTINUE
      EVERR=(PL-PR)/PR
      USR=UR+CRG*EVERR/DSQRT(1.+G6*EVERR)
      SR=USR
      UEL=UL-G7*CL*(ZETAR-ZETAL)/ZETAL
      SL=UEL
      NL=2
      NR=2
      IF (USR.GE.UL) NL=1
      IF (UEL.LE.UR) NR=1
      IF (DABS(EVERR).LT.EPS) GO TO 100
      IF (NL.EQ.2.AND.NR.EQ.1) GO TO 7001
      GO TO 100
C RIGHT PRESSURE IS HIGHER
102 CONTINUE
      EVERL=(PR-PL)/PL
      USL=UL-CLG*EVERL/DSQRT(1.+G6*EVERL)
      SL=USL
      UER=UR+G7*CR*(ZETAL-ZETAR)/ZETAR
      SR=UER
      NL=2
      NR=2
      IF (UER.GE.UL) NL=1
      IF (USL.LE.UR) NR=1
      IF (DABS(EVERL).LT.EPS) GO TO 100
      IF (NL.EQ.1.AND.NR.EQ.2) GO TO 7001
      GO TO 100
100 CONTINUE
      IF (NL.EQ.1.AND.NR.EQ.2) NCASE=1
      IF (NL.EQ.2.AND.NR.EQ.2) NCASE=2
      IF (NL.EQ.2.AND.NR.EQ.1) NCASE=3
      IF (NL.EQ.1.AND.NR.EQ.1) NCASE=4
      IF (DABS(PL-PR)+DABS(UL-UR).LT.EPS*(PMAX-UMIN)) NCASE=4
      UMIDA=EPS*DMAX1(CL,CR)
      DUDZL=-G7*CL/ZETAL
      DUDZR= G7*CR/ZETAR
      ZETA=(-(UR-UL)+ZETAR*DUDZR-ZETAL*DUDZL)/(DUDZR-DUDZL)
      IF (ZETA.LE.0.) GO TO 7002
      N=0
      GO TO (1,2,3,4), NCASE
C THE CASE ES
1 ITYPE=NCASE
  HELEML=.FALSE.
  HELEMR=.TRUE.
11 N=N+1
  IF (N.GT.NMAX) GO TO 7003
  ZETAF=ZETA
  UEL=UL-G7*CL*(ZETAF-ZETAL)/ZETAL
  PPR=(ZETAF/ZETAR)**NG
  EVERR=PPR-1.
  SQRR=DSQRT(1.+G6*EVERR)
  USR=UR+CRG*EVERR/SQRR
  DU=UEL-USR
  IF (DABS(DU).LE.UMIDA) GO TO 10
  DUDZR=NG*CRG*(PPR/ZETAF)*(1.+G9*EVERR)/SQRR**3
  ZETA=ZETAF+DU/(DUDZR-DUDZL)
  GO TO 11
10 CONTINUE
  USTAR=(UEL+USR)/2.
  PSTAR=PPR*PR
  CSTARL=CL+(UL-USTAR)/G7
  RSTARL=GAMA*PSTAR/CSTARL**2
  GSTARL=CSTARL*RSTARL
C EQU. NO. 69.01 OF THE BOOK BY COURANT-FRIEDRICHS.
  WWR=G11*(USTAR-UR)*ROR
  WR=WWR+DSQRT(GR**2+WWR**2)
  RSTARR=ROR*WR/(WR-ROR*(USTAR-UR))
  GSTARR=DSQRT(GAMA*PSTAR*RSTARR)
  CSTARR=GSTARR/RSTARR

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	WRE=WR/ROR+UR	HFL0937
	UW(1)=UL-CL	HFL0938
	UW(2)=USTAR-CSTARL	HFL0939
	UW(3)=USTAR	HFL0940
	UW(4)=WRE	HFL0941
	UW(5)=WRE	HFL0942
	GO TO 5	HFL0943
C	THE CASE SS	HFL0944
2	ITYPE=NCASE	HFL0945
	HELEML=.TRUE.	HFL0946
	HELEMR=.TRUE.	HFL0947
21	N=N+1	HFL0948
	IF (N.GT.NMAX) GO TO 7003	HFL0949
	ZETAF=ZETA	HFL0950
	PF=ZETAF**NG	HFL0951
	PPL=PF/PL	HFL0952
	PPR=PF/PR	HFL0953
	EVERL=PPL-1.	HFL0954
	EVERR=PPR-1.	HFL0955
	SQRL=DSQRT(1.+G6*EVERL)	HFL0956
	SQRR=DSQRT(1.+G6*EVERR)	HFL0957
	USL=UL-CLG*EVERL/SQRL	HFL0958
	USR=UR+CRG*EVERR/SQRR	HFL0959
	DU=USL-USR	HFL0960
	IF (DABS(DU).LE.UMIDA) GO TO 20	HFL0961
	DUDZL=-NG*CLG*(PPL/ZETAF)*(1.+G9*EVERL)/SQRL**3	HFL0962
	DUDZR= NG*CRG*(PPR/ZETAF)*(1.+G9*EVERR)/SQRR**3	HFL0963
	ZETA=ZETAF+DU/(DUDZR-DUDZL)	HFL0964
	GO TO 21	HFL0965
20	CONTINUE	HFL0966
	USTAR=(USL+USR)/2.	HFL0967
	PSTAR=(PPL*PL+PPR*PR)/2.	HFL0968
	WWR=G11*(USTAR-UR)*ROR	HFL0969
	WR=WWR+DSQRT(GR**2+WWR**2)	HFL0970
	WWL=-G11*(USTAR-UL)*ROL	HFL0971
	WL=WWL+DSQRT(GL**2+WWL**2)	HFL0972
	RSTARL=ROL*WL/(WL+ROL*(USTAR-UL))	HFL0973
	RSTARR=ROR*WR/(WR-ROR*(USTAR-UR))	HFL0974
	GSTARL=DSQRT(GAMA*PSTAR*RSTARL)	HFL0975
	GSTARR=DSQRT(GAMA*PSTAR*RSTARR)	HFL0976
	CSTARL=GSTARL/RSTARL	HFL0977
	CSTARR=GSTARR/RSTARR	HFL0978
	WLE=-WL/ROL+UL	HFL0979
	WRE=WR/ROR+UR	HFL0980
	UW(1)=WLE	HFL0981
	UW(2)=WLE	HFL0982
	UW(3)=USTAR	HFL0983
	UW(4)=WRE	HFL0984
	UW(5)=WRE	HFL0985
	GO TO 5	HFL0986
C	THE CASE SE	HFL0987
3	ITYPE=NCASE	HFL0988
	HELEML=.TRUE.	HFL0989
	HELEMR=.FALSE.	HFL0990
31	N=N+1	HFL0991
	IF (N.GT.NMAX) GO TO 7003	HFL0992
	ZETAF=ZETA	HFL0993
	UER=UR+G7*CR*(ZETAF-ZETAR)/ZETAR	HFL0994
	PPL=(ZETAF/ZETAL)**NG	HFL0995
	EVERL=PPL-1.	HFL0996
	SQRL=DSQRT(1.+G6*EVERL)	HFL0997
	USL=UL-CLG*EVERL/SQRL	HFL0998
	DU=USL-UER	HFL0999
	IF (DABS(DU).LE.UMIDA) GO TO 30	HFL1000
	DUDZL=-NG*CLG*(PPL/ZETAF)*(1.+G9*EVERL)/SQRL**3	HFL1001
	ZETA=ZETAF+DU/(DUDZR-DUDZL)	HFL1002
	GO TO 31	HFL1003
30	CONTINUE	HFL1004
	USTAR=(USL+UER)/2.	HFL1005
	PSTAR=PPL*PL	HFL1006
	CSTARR=CR-(UR-USTAR)/G7	HFL1007
	RSTARR=GAMA*PSTAR/CSTARR**2	HFL1008

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GSTARR=CSTARR*RSTARR
WWL=-G11*(USTAR-UL)*ROL
WL=WWL+DSQRT(GL**2+WWL**2)
WLE=-WL/ROL+UL
RSTARL=ROL*WL/(WL+ROL*(USTAR-UL))
GSTARL=DSQRT(GAMA*PSTAR*RSTARL)
CSTARL=GSTARL/RSTARL
UW(1)=WLE
UW(2)=WLE
UW(3)=USTAR
UW(4)=USTAR+CSTARR
UW(5)=UR+CR
GO TO 5
C THE CASE EE
4 ITYPE=NCASE
HELEML=.FALSE.
HELEMR=.FALSE.
PSTAR=ZETA**NG
USTAR=UL-G7*CL*(ZETA-ZETAL)/ZETAL
CSTARL=CL+(UL-USTAR)/G7
CSTARR=CR-(UR-USTAR)/G7
RSTARL=GAMA*PSTAR/CSTARL**2
RSTARR=GAMA*PSTAR/CSTARR**2
GSTARL=RSTARL*CSTARL
GSTARR=RSTARR*CSTARR
UW(1)=UL-CL
UW(2)=USTAR-CSTARL
UW(3)=USTAR
UW(4)=USTAR+CSTARR
UW(5)=UR+CR
N=1
GO TO 5
5 CONTINUE
DO 6 K=1,6
NFLUX=K
IF (UW(K).GE.0.) GO TO 61
6 CONTINUE
NFLUX=6
61 CONTINUE
C MIN(I)=MIN(I).OR.NCASE
C MIN(I)=MIN(I).OR.SHIFT(N,3)
C MIN(I)=MIN(I).OR.SHIFT(NFLUX,9)
C NC14(NCASE)=NC14(NCASE)+1
C CASEAV(NCASE)=CASEAV(NCASE)+N
C NF16(NFLUX)=NF16(NFLUX)+1
IF(A(3).NE.0.)GO TO 666
IF(I.NE.2) GO TO 666
PRINT 667,I,NFLUX,NCASE,PL,UL,ROL,PR,UR,ROR,USTAR,PSTAR,RSTARL,
RSTARR,(KK,UW(KK),KK=1,6)
667 FORMAT(/1X,'I,NFLUX,NCASE=',3I5/1X,'PL,UL,ROL,PR,UR,ROR=',6D12.4/
1 1X,'USTAR,PSTAR,RSTARL,RSTARR=',4D13.4/
2 1X,'KK,UW(KK)=' ,6(I4,2X,D13.4)/)
666 CONTINUE
RETURN
7001 CONTINUE
PRINT 7101, PL,UL,PR,UR,ZETAL,ZETAR,SL,SR,NL,NR,I
7101 FORMAT(/1X,'FROM RIEMAN. AN IMPOSSIBLE CASE OF EXPANSION/SHOCK'
1 //1X,'PL,UL,PR,UR=',4D25.14//
2 1X,'ZETAL,ZETAR,SL,SR=',4D25.14//
3 1X,'NL,NR,I=' ,3I10//)
CALL SOF(7001)
7002 CONTINUE
PRINT 7102, ZETA,DUDZL,DUDZR,ZETAL,ZETAR,PL,UL,PR,UR,N,NCASE,I
7102 FORMAT(/1X,'FROM RIEMAN. NEGATIVE PRESSURE AT THE INTERSECTION',
1 1X,'OF L AND R EXPANSION BRANCHES'//
2 1X,'IT MEANS THAT A CAVITATION TENDS TO FORM. THIS',
3 1X,'POSSIBILITY IS EXCLUDED IN PRESENT VERSION'//
4 1X,'ZETA,DUDZL,DUDZR,ZETAL,ZETAR,PL,UL,PR,UR=',9D10.3//
5 1X,'N,NCASE,I=' ,3I10//)
CALL SOF(7002)
7003 CONTINUE
PRINT 7103, I,N,NCASE,DU,UMIDA,EPS,PL,UL,PR,UR,

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HFL1009
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HFL1080


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1          ZETA,ZETAF,ZETAL,ZETAR,DUDZL,DUDZR      HFL1081
7103 FORMAT(//1X,'FROM RIEMAN.  NUMBER OF ITERATIONS EXCEEDED.'// HFL1082
1          1X,'I,N,NCASE,DU,UMIDA,EPS=',3I6,3D18.6// HFL1083
2          1X,'PL,UL,PR,UR,ZETA,ZETAF=',6D18.10// HFL1084
3          1X,'ZETAL,ZETAR,DUDZL,DUDZR=',4D18.10//) HFL1085
          CALL SOF(7003) HFL1086
          RETURN HFL1087
          END HFL1088
          SUBROUTINE MAGA(L,I,MIN) HFL1089
          IMPLICIT REAL*8(A-H,O-Z,$) HFL1090
          DIMENSION MIN(L) HFL1091
          COMMON /GAM/GAMA,NG,MU2,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11 HFL1092
1          ,G12,G13,G14,G15,G16,G17,G18,G19,G20 HFL1093
          REAL*8 NG HFL1094
          REAL*8 MU2 HFL1095
          COMMON /STEP0/UL,PL,ROL,GL,UR,PR,ROR,GR,USTAR,PSTAR, HFL1096
1          RSTARL,RSTARR,GSTARL,GSTARR,WL,WR, HFL1097
2          CL,CR,CSTARL,CSTARR,UW(6) HFL1098
3          ,ZL,ZR,ZSTARL,ZSTARR,NFLUX,HELEML,HELEMR HFL1099
          LOGICAL HELEML,HELEMR HFL1100
          COMMON /STEP1/DUIDT,DPIDT,DGIDTL,DGIDTR,DRIDTL,DRIDTR HFL1101
2          ,ASTARL,ASTARR HFL1102
3          ,RAT,SH HFL1103
          COMMON /GRADS/DUDXIL,DPDXIL,DGDXIL,DRDXIL, HFL1104
1          DUDXIR,DPDXIR,DGDXIR,DRDXIR HFL1105
          COMMON /AB/A(50) HFL1106
          REAL LU,LP,LRO HFL1107
          DATA EPS/1.D-6/ HFL1108
C***** HFL1109
C WE HERE SOLVE FOR THE TIME-DERIVATIVES ALONG THE CONTACT SURFACE, HFL1110
C NAMELY DUIDT,DPIDT. FROM THESE WE ALSO OBTAIN THE OTHER HFL1111
C TIME-DERIVATIVES (SEE COMMON /STEP1/). HFL1112
C WE COMPUTE THE COEFFICIENTS FOR TWO EQUATIONS FOR DUIDT,DPIDT. THESE HFL1113
C ARE AAL*DUIDT+BBL*DPIDT=CCL HFL1114
C AAR*DUIDT+BBR*DPIDT=CCR HFL1115
C***** HFL1116
C IF(SH.LE.EPS)RAT=0. HFL1117
C IF (.NOT.HELEML) GO TO 12 HFL1118
11 CONTINUE HFL1119
DP=PSTAR-PL HFL1120
IF (DABS(DP).LT.EPS*PSTAR) GO TO 12 HFL1121
DU=USTAR-UL HFL1122
Z1=1./DP HFL1123
Z2=0.5/(PSTAR+MU2*PL) HFL1124
ZA=Z1-Z2 HFL1125
ZB=Z1+MU2*Z2 HFL1126
LU=-ROL*DU*(GAMA*PL*ZB+0.5)+WL HFL1127
LRO=0.5*DP/ROL HFL1128
LP=1.+ZB*DP HFL1129
AAL=1.+ZA*DP HFL1130
BBL=-ZA*DU+WL/GSTARL**2 HFL1131
CCL=-LU*DUDXIL-LRO*DRDXIL-LP*DPDXIL HFL1132
CCL=CCL-WL*USTAR*RAT/RSTARL HFL1133
1 +UL*RAT*DU*(GAMA*PL*ZB+0.5) HFL1134
GO TO 10 HFL1135
12 CONTINUE HFL1136
A1=DUDXIL+DPDXIL/GL HFL1137
BETA=GSTARL/GL HFL1138
ASTARL=A1+(G3/GL)*(CL*DGDXIL-G4*DPDXIL)*(BETA**G5-1.) HFL1139
AAL=1. HFL1140
BBL=1./GSTARL HFL1141
CCL=-GSTARL*ASTARL/DSQRT(BETA) HFL1142
GEOM=RAT*((GAMA-1.)*UL+2.*CL)* HFL1143
1 (BETA**G13-1.)/(ROL*(GAMA-3.)) HFL1144
1 -4.*RAT*CL*(BETA**G14-1.)/(ROL*(3.*GAMA-5.)) HFL1145
ASTARL=ASTARL-GEOM HFL1146
EVER1= GSTARL*GEOM/DSQRT(BETA) HFL1147
EVER2=-RAT*USTAR*CSTARL HFL1148
CCL=CCL+EVER1+EVER2 HFL1149
GO TO 10 HFL1150
10 CONTINUE HFL1151
IF (.NOT.HELEMR) GO TO 22 HFL1152

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21  CONTINUE                                     HFL1153
    DP=PSTAR-PR                                   HFL1154
    IF (DABS(DP).LT.EPS*PSTAR) GO TO 22          HFL1155
    DU=USTAR-UR                                   HFL1156
    Z1=1./DP                                       HFL1157
    Z2=0.5/(PSTAR+MU2*PR)                         HFL1158
    ZA=Z1-Z2                                       HFL1159
    ZB=Z1+MU2*Z2                                   HFL1160
    LU=-ROR*DU*(GAMA*PR*ZB+0.5)-WR               HFL1161
    LRO=0.5*DP/ROR                               HFL1162
    LP=1.+ZB*DP                                    HFL1163
    AAR=1.+ZA*DP                                   HFL1164
    BBR=-ZA*DU-WR/GSTARR**2                       HFL1165
    CCR=-LU*DUDXIR-LRO*DRDXIR-LP*DPDXIR          HFL1166
    CCR=CCR+WR*USTAR*RAT/RSTARR                  HFL1167
1    +UR*RAT*DU*(GAMA*PR*ZB+0.5)                 HFL1168
    GO TO 20                                       HFL1169
22  CONTINUE                                     HFL1170
    A1=DUDXIR-DPDXIR/GR                           HFL1171
    BETA=GSTARR/GR                                 HFL1172
    ASTARR=A1-(G3/GR)*(CR*DGDIXIR-G4*DPDXIR)*(BETA**G5-1.) HFL1173
    AAR=1.                                         HFL1174
    BBR=-1./GSTARR                                HFL1175
    CCR=GSTARR*ASTARR/DSQRT(BETA)                 HFL1176
    GEOM=RAT*(-(GAMA-1.)*UR+2.*CR)*(BETA**G13-1.) HFL1177
1    /(ROR*(GAMA-3.))                             HFL1178
2    -4.*RAT*CR*(BETA**G14-1.)/(ROR*(3.*GAMA-5.)) HFL1179
    ASTARR=ASTARR+GEOM                            HFL1180
    EVER1=GSTARR*GEOM/DSQRT(BETA)                 HFL1181
    EVER2=RAT*USTAR*CSTARR                        HFL1182
    CCR=CCR+EVER1+EVER2                           HFL1183
    GO TO 20                                       HFL1184
20  CONTINUE                                     HFL1185
    DET=AAL*BBR-AAR*BBL                           HFL1186
    DUIDT=(CCL*BBR-CCR*BBL)/DET                   HFL1187
    DPIDT=-(CCL*AAR-CCR*AAL)/DET                  HFL1188
    DRIDTL=DPIDT/CSTARR**2                         HFL1189
    DRIDTR=DPIDT/CSTARR**2                         HFL1190
    DGIDTL=0.5*GSTARR*(DPIDT/PSTAR+DRIDTL/RSTARR) HFL1191
    DGIDTR=0.5*GSTARR*(DPIDT/PSTAR+DRIDTR/RSTARR) HFL1192
    RETURN                                         HFL1193
    END                                           HFL1194
SUBROUTINE FLUXE(L,I,MIN)                         HFL1195
IMPLICIT REAL*8(A-H,O-Z,$)                       HFL1196
DIMENSION MIN(L)                                  HFL1197
COMMON /AB/A(50)                                  HFL1198
EQUIVALENCE (DT,A(4)),(NCYC,A(12))               HFL1199
COMMON /GAM/GAMA,NG,MU2,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11 HFL1200
1    ,G12,G13,G14,G15,G16,G17,G18,G19,G20        HFL1201
    REAL*8 NG                                       HFL1202
    REAL*8 MU2                                       HFL1203
    COMMON /GRADS/DUDXIL,DPDXIL,DGDIXIL,DRDXIL,   HFL1204
1    DUDXIR,DPDXIR,DGDIXIR,DRDXIR                HFL1205
    COMMON /STEP0/UL,PL,ROL,GL,UR,PR,ROR,GR,USTAR,PSTAR, HFL1206
1    RSTARR,GSTARR,GSTARR,WL,WR,                  HFL1207
2    CL,CR,CSTARR,CSTARR,UW(6)                    HFL1208
3    ,ZL,ZR,ZSTARR,ZSTARR,NFLUX,HELEML,HELEMR    HFL1209
    LOGICAL HELEML,HELEMR                         HFL1210
    COMMON /STEP1/DUIDT,DPIDT,DGIDTL,DGIDTR,DRIDTL,DRIDTR HFL1211
2    ,ASTARR,ASTARR                                HFL1212
3    ,RAT,SH                                         HFL1213
    COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,PODET,ROODET HFL1214
    COMMON /FI/FIH1,FIH2,FIH3,UXN,PXN,GXN,ROXN    HFL1215
1    ,GIH                                           HFL1216
2    ,FIH4,ZMDOTL,ZMDOTR                           HFL1217
    COMMON /PRNT/ROX,PX,UX,ZX                     HFL1218
C*****                                           HFL1219
    ENTRY FLUXE1(L,I,MIN)                          HFL1220
C*****                                           HFL1221
    DT2=DT/2.                                       HFL1222
    GO TO (1,2,3,4,5,6),NFLUX                     HFL1223
1    CONTINUE                                       HFL1224

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	DUDXIX=DUDXIL	HFL1225
	DRDXIX=DRDXIL	HFL1226
	DPDXIX=DPDXIL	HFL1227
	DGDIX=0.5*GL*(DPDXIL/PL+DRDXIL/ROL)	HFL1228
	DUDTX=-DPDXIL	HFL1229
	DRODTX=-ROL**2*DUDXIL	HFL1230
	DPDTX=-GL**2*DUDXIL	HFL1231
	DRODTX=DRODTX-RAT*ROL*UL	HFL1232
	DPDTX=DRODTX*CL**2	HFL1233
	DGDTX=G6*GL*DPDTX/PL	HFL1234
	UX=UL	HFL1235
	PX=PL	HFL1236
	ROX=ROL	HFL1237
	ZX=ZL	HFL1238
	GX=GL	HFL1239
	GO TO 9	HFL1240
6	CONTINUE	HFL1241
	DUDXIX=DUDXIR	HFL1242
	DPDXIX=DPDXIR	HFL1243
	DRDXIX=DRDXIR	HFL1244
	DGDIX=0.5*GR*(DPDXIR/PR+DRDXIR/ROR)	HFL1245
	DUDTX=-DPDXIR	HFL1246
	DPDTX=-GR**2*DUDXIR	HFL1247
	DRODTX=-ROR**2*DUDXIR	HFL1248
	DRODTX=DRODTX-RAT*ROR*UR	HFL1249
	DPDTX=DRODTX*CR**2	HFL1250
	DGDTX=G6*GR*DPDTX/PR	HFL1251
	UX=UR	HFL1252
	PX=PR	HFL1253
	ROX=ROR	HFL1254
	ZX=ZR	HFL1255
	GX=GR	HFL1256
	GO TO 9	HFL1257
2	CONTINUE	HFL1258
	BETA0=(MU2*(UL/CL+G7))**(1./MU2)	HFL1259
	A1=DUDXIL+DPDXIL/GL	HFL1260
	A0=A1+(G3/GL)*(CL*DGDIX-G4*DPDXIL)*(BETA0**G5-1.)	HFL1261
	EVER1=-((GAMA-1)*UL+2*CL)*(BETA0**G13-1.)/(GAMA-3.)	HFL1262
	EVER2=4.*CL*(BETA0**G14-1.)/(3.*GAMA-5.)	HFL1263
	EVER=(EVER1+EVER2)*RAT/ROL	HFL1264
	A0=(A0+EVER)	HFL1265
	DUDAX=A0	HFL1266
	DPDAX=GL*BETA0*A0	HFL1267
	C0=MU2*(UL+G7*CL)	HFL1268
	UX=C0	HFL1269
	ROX=GL*BETA0/C0	HFL1270
	ZX=ZSTARL	HFL1271
	PX=ROX*C0**2/GAMA	HFL1272
	GX=ROX*C0	HFL1273
	DRODAX=ROL*BETA0**((1./G4)	HFL1274
1	*(DRDXIL/ROL-DPDXIL/(GAMA*PL))*DSQRT(BETA0)	HFL1275
2	+A0/C0)	HFL1276
	DGDAX=BETA0*DSQRT(BETA0)*(DGDIX-G4*DPDXIL/CL)	HFL1277
1	+G4*ROL*A0*BETA0**((1./G4)	HFL1278
	DPDAX=DPDAX+RAT*UX*C0*DSQRT(BETA0)	HFL1279
	G41=1./G4+0.5	HFL1280
	DRODAX=(DRDXIL-DPDXIL/(CL*CL))*BETA0**G41+DPDAX/(C0*C0)	HFL1281
	DGDAX=0.5*GAMA*(PX*DRODAX+ROX*DPDAX)/GX	HFL1282
	DUDBX=-CL*BETA0**((-1./G4)/G4	HFL1283
	DPDBX=PL*BETA0**MU2/G6	HFL1284
	DRODBX=ROL*BETA0**((-MU2)/G4	HFL1285
	DGDBX=GL	HFL1286
	GO TO 9	HFL1287
5	CONTINUE	HFL1288
	BETA0=(MU2*(-UR/CR+G7))**(1./MU2)	HFL1289
	A1=DUDXIR-DPDXIR/GR	HFL1290
	A0=A1+(G3/GR)*(-CR*DGDIX+G4*DPDXIR)*(BETA0**G5-1.)	HFL1291
	EVER1=-((GAMA-1)*UR+2*CR)*(BETA0**G13-1.)/(GAMA-3.)	HFL1292
	EVER2=-4.*CR*(BETA0**G14-1.)/(3.*GAMA-5.)	HFL1293
	EVER=(EVER1+EVER2)*RAT/ROR	HFL1294
	A0=(A0+EVER)	HFL1295
	DUDAX=A0	HFL1296


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DPDAX=-GR*BETA0*A0
C0=MU2*(-UR+G7*CR)
DRODAX=-ROR*BETA0*(1./G4)
1      *((-DRDXIR/ROR+DPDXIR/(GAMA*PR))*DSQRT(BETA0)
2      +A0/C0)
UX=-C0
ROX=GR*BETA0/C0
ZX=ZSTARR
PX=ROX*C0**2/GAMA
GX=ROX*C0
DGDAX=BETA0*DSQRT(BETA0)*(-DGDIXIR+G4*DPDXIR/CR)
1      +G4*ROR*A0*BETA0*(1./G4)
DGDAX=-DGDAX
DPDAX=DPDAX-RAT*UX*C0*DSQRT(BETA0)
G41=1./G4+0.5
DRODAX=(DRDXIR-DPDXIR/(CR*CR)) *BETA0**G41+DPDAX/(C0*C0)
DGDAX=0.5*GAMA*(PX*DRODAX+ROX*DPDAX)/GX
DUDBX=CR*BETA0*(-1./G4)/G4
DPDBX=PR*BETA0**MU2/G6
DRODBX=ROR*BETA0*(-MU2)/G4
DGDIX=GR
GO TO 9
3 CONTINUE
UX=USTAR
PX=PSTAR
ROX=RSTARL
ZX=ZSTARL
GX=GSTARL
DUDIX=-DPIDT/GSTARL**2
DPDXIX=-DUIDT
DUDIX=DUDIX-RAT*USTAR/RSTARL
IF (.NOT.HELEML) GO TO 32
31 CONTINUE
DRDXIX=(RSTARL/WL)**2*(3.*DUIDT+DPIDT*(1.+3.*(WL/GSTARL)**2)/WL
1      +DUDIX*WL*((GL/WL)**2+3.)+3.*DPDXIL
2      +DRDXIL*(WL/ROL)**2)
EVER1=UL*RSTARL**2*RAT*((GL/WL)**2+1.)/(ROL*WL)
EVER2=2.*RSTARL*USTAR*RAT/WL
DRDXIX=DRDXIX+EVER1+EVER2
GO TO 33
32 CONTINUE
BETA=GSTARL/GL
SQB=DSQRT(BETA)
DRODA=ROL*BETA*(1./G4)*(SQB*(DRDXIL/ROL-DPDXIL/(GAMA*PL))
1      +ASTARL/CSTARL)
DRDXIX=DRODA/SQB+DPIDT/(GSTARL*CSTARL**2)
DPDA=GSTARL*(ASTARL+RAT*USTAR*CSTARL/(GL* SQB))
G41=1./G4+0.5
DRODA=(DRDXIL-DPDXIL/(CL*CL)) *BETA**G41+DPDA/(CSTARL**2)
DRDXIX= DRODA/SQB+DPIDT/(GSTARL*CSTARL**2)
33 CONTINUE
DGDIX=0.5*GX*(DPDXIX/PX+DRDXIX/ROX)
DUDTX=DUIDT
DPDTX=DPIDT
DGDIX=G6*GSTARL*DPIDT/PSTAR
DRODTX=DPIDT/CSTARL**2
GO TO 9
4 CONTINUE
UX=USTAR
PX=PSTAR
ROX=RSTARR
ZX=ZSTARR
GX=GSTARR
DUDIX=-DPIDT/GSTARR**2
DUDIX=DUDIX-RAT*USTAR/RSTARR
DPDXIX=-DUIDT
IF (.NOT.HELEMR) GO TO 42
41 CONTINUE
DRDXIX=(RSTARR/WR)**2*(3.*DUIDT-DPIDT*(1.+3.*(WR/GSTARR)**2)/WR
1      -DUDIX*WR*((GR/WR)**2+3.)+3.*DPDXIR
2      +DRDXIR*(WR/ROR)**2)
EVER1=UR*RSTARR**2*RAT*((GR/WR)**2+1.)/(ROR*WR)
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EVER2=2.*RSTARR*USTAR*RAT/WR
DRDXIX=DRDXIX-EVER1-EVER2
GO TO 43
42 CONTINUE
BETA=GSTARR/GR
SQB=DSQRT(BETA)
DRODA=-ROR*BETA**((1./G4)*(SQB*(-DRDXIR/ROR+DPDXIR/(GAMA*PR))
1 +ASTARR/CSTARR)
DRDXIX=DRODA/SQB-DPIDT/(GSTARR*CSTARR**2)
DPDA=-GSTARR*(ASTARR+RAT*USTAR*CSTARR/(GR* SQB))
G41=1./G4+0.5
DRODA=(DRDXIR-DPDXIR/(CR*CR)) *BETA**G41+DPDA/(CSTARR**2)
43 DRDXIX= DRODA/SQB-DPIDT/(GSTARR*CSTARR**2)
CONTINUE
DGDIX=0.5*GX*(DPDXIX/PX+DRDXIX/ROX)
DUDTX=DUIDT
DPDTX=DPIDT
DGDIX=G6*GSTARR*DPIDT/PSTAR
DRODTX=DPIDT/CSTARR**2
GO TO 9
9 CONTINUE
RETURN
C*****
ENTRY FLUXE2(L,I,MIN)
C*****
FI1=ROX*UX
FI2=ROX*UX**2+PX
FI2=FI2-PX
FI3=UX*(G12*PX+0.5*ROX*UX**2+ZX*ROX*QDET)
FI4=ZX*ROX*UX
ROU00=ROX*UX
GO TO(10,20,30,40,50,60), NFLUX
10 CONTINUE
60 CONTINUE
DFDXI1=DRDXIX*UX+ROX*DUDIX
DFDXI2=DRDXIX*UX**2+2.*ROX*UX*DUDIX+DPDXIX
DFDXI2=DFDXI2-DPDXIX
DFDXI3=DUDIX*(G12*PX+0.5*ROX*UX**2)
1 +UX*(G12*DPDXIX+0.5*DRDXIX*UX**2+ROX*UX*DUDIX)
DFIDT1=DRODTX*UX+ROX*DUDTX
DFIDT2=DRODTX*UX**2+2.*ROX*UX*DUDTX+DPDTX
DFIDT2=DFIDT2-DPDTX
DFIDT3=DUDTX*(G12*PX+0.5*ROX*UX**2)
1 +UX*(G12*DPDTX+0.5*DRODTX*UX**2+ROX*UX*DUDTX)
FIDOT1=-ROU00*DFDXI1+DFIDT1
FIDOT2=-ROU00*DFDXI2+DFIDT2
FIDOT3=-ROU00*DFDXI3+DFIDT3
UXDOT=-ROU00*DUDIX+DUDTX
PXDOT=-ROU00*DPDXIX+DPDTX
GXDOT=-ROU00*DGDIX+DGDIX
ROXDOT=-ROU00*DRDXIX+DRODTX
FIH1=FI1+DT2*FIDOT1
FIH2=FI2+DT2*FIDOT2
GIH=PX+DT2*PXDOT
FIH3=FI3+DT2*FIDOT3
FIH4=FI4
UXN=UX+DT*UXDOT
PXN=PX+DT*PXDOT
GXN=GX+DT*GXDOT
ROXN=ROX+DT*ROXDOT
GO TO 90
20 CONTINUE
EVO=GL*DSQRT(BETA0)
201 CONTINUE
DFIDA1=DRODAX*UX+ROX*DUDAX
DFIDA2=DRODAX*UX**2+2.*ROX*UX*DUDAX+DPDAX
DFIDA2=DFIDA2-DPDAX
DFIDA3=DUDAX*(G12*PX+0.5*ROX*UX**2)
1 +UX*(G12*DPDAX+0.5*DRODAX*UX**2+ROX*UX*DUDAX)
FIDOT1=-EVO*DFIDA1
FIDOT2=-EVO*DFIDA2
FIDOT3=-EVO*DFIDA3

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	FIH1=FI1+DT2*FIDOT1	HFL1441
	FIH2=FI2+DT2*FIDOT2	HFL1442
	FIH3=FI3+DT2*FIDOT3	HFL1443
	FIH4=FI4	HFL1444
	GA=DGDAX	HFL1445
	IF(NFLUX.EQ.5)GA=-GA	HFL1446
	DROUA=UX*DRODAX+ROX*DUDAX	HFL1447
	BETAPR=0.5*DSQRT(BETA0)*(GA-DROUA)	HFL1448
	FIH2=FIH2-DPDBX*BETAPR*DT2	HFL1449
	UXDOT=-EV0*DUDAX+BETAPR*DUDBX	HFL1450
	PXDOT=-EV0*DPDAX+BETAPR*DPDBX	HFL1451
	GIH=PX+DT2*PXDOT	HFL1452
	GXDOT=-EV0*DGDAX+BETAPR*DGDBX	HFL1453
	ROXDOT=-EV0*DRODAX+BETAPR*DRODBX	HFL1454
	UXN=UX+DT*UXDOT	HFL1455
	PXN=PX+DT*PXDOT	HFL1456
	GXN=GX+DT*GXDOT	HFL1457
	ROXN=ROX+DT*ROXDOT	HFL1458
	GO TO 90	HFL1459
50	CONTINUE	HFL1460
	EV0=-GR*DSQRT(BETA0)	HFL1461
	GO TO 201	HFL1462
30	CONTINUE	HFL1463
40	CONTINUE	HFL1464
	GO TO 60	HFL1465
90	CONTINUE	HFL1466
	RETURN	HFL1467
	END	HFL1468

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